February 14, 1928. SPECIAL NUMBER. Price 2s. 6d.

# GAS JOURNAL

## LIGHT ✦ HEAT ✦ POWER ✦ BYE-PRODUCTS

[Founded in 1849 as the "Journal of Gas Lighting."]

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## Carbonization Conference Papers

## Birmingham : Feb. 21-24, 1928.


The Woodall-Duckham Companies,
Allington House,
136, Victoria Street, London, S.W. 1.
See advertisement on p. 16.

GLOVER - WEST VERTICAL RETORTS
WEST'S GAS IMPROVEMENT, Co., Ltd.,
Manchester.
London Office: Regent House, Kingsway, W.C. 2.
See illustrated advert. on pp. 24-25.

"SOMETHING NEW."
See advertisement on p. 5.
ALDRIDGE & RANKEN, LTD.,
BATH and LONDON.

WATERLESS GASHOLDERS.
Waterless Gasholder Co., Ltd.
E. COCKEY & SONS, LTD.
R & J. DEMPSTER, LTD.
ROBERT DEMPSTER & SONS, LTD.
See advertisement on page 12.

Coal Distillation
THE
CROZIER PROCESS
See advertisement on p. 9

W. C. HOLMES & Co. Ltd.
HUDDERSFIELD.
See advertisement on p. 112.

DRAKE'S VERTICALS
See advertisement on p. 30.

Chemical Engineering and
Wilton's Patent Furnace Co., Ltd.
*Tar Distillation and Dehydration Plants—S/A Plant*
*Furnaces—Coke Ovens and Bye-Product Plant*
See advertisements, pp. 48, 49.

*See*
RADIATION
Advertisement on p. 82.

FOR SPECIAL TEST METERS
Pressure Recorders, etc.
Alder & Mackay Ltd
Established 1850
*Gas Meter Manufacturers,*
EDINBURGH : LONDON : BRADFORD
See advertisement on p. 3.

DRY GAS METERS.
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See illustrated advertisement, p. 6.

"WHESSOE"
*for Gas Works Plant.*
See advertisement, page iii. of cover.

ROBERT CORT
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READING.
COKE GRADING AND CUTTING PLANT AN • ANTI-DIP VALVES.
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See advertisement on p. 100.

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Manufacturers of the highest grade of Refractory Fire Bricks, specially suited for furnaces subjected to the highest heats and sudden changes of temperature.

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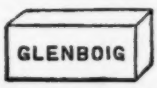
TRADE 

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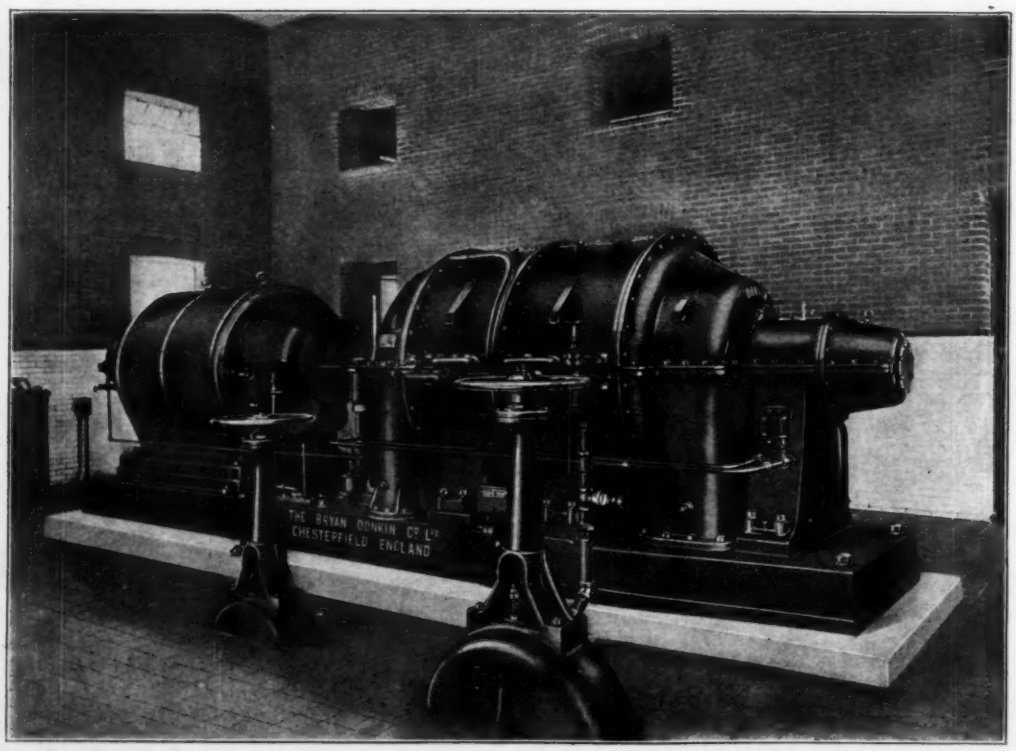


Fig. No. 775.

View of a Rateau Seven-Stage Turbo Compressor driven by a 1500 B.H.P. Electric Motor, to pass 1,000,000 c.ft. of gas per hr. at 3,750 r.p.m. against 15 lbs. pressure—supplied to the Montreal Light Heat & Power Co.

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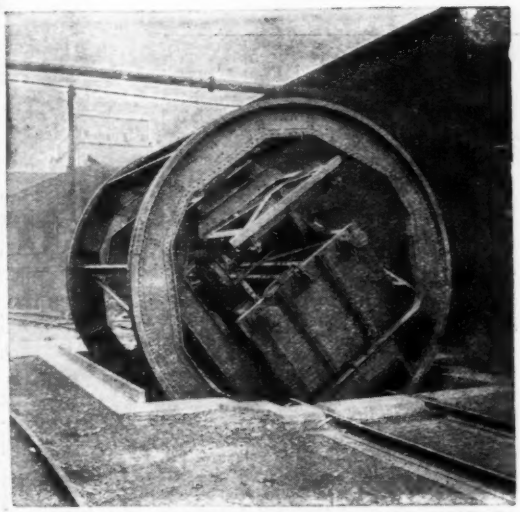

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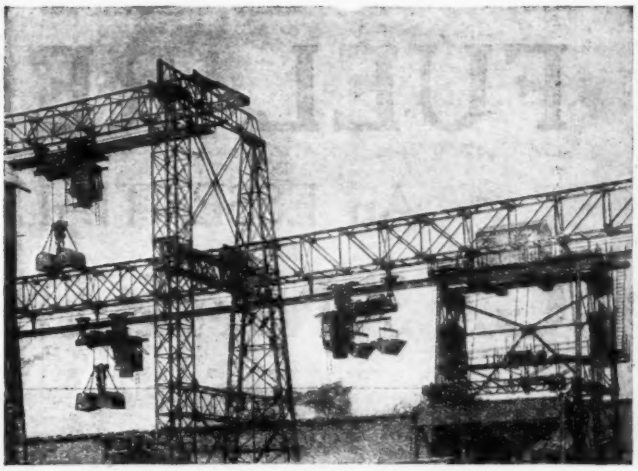

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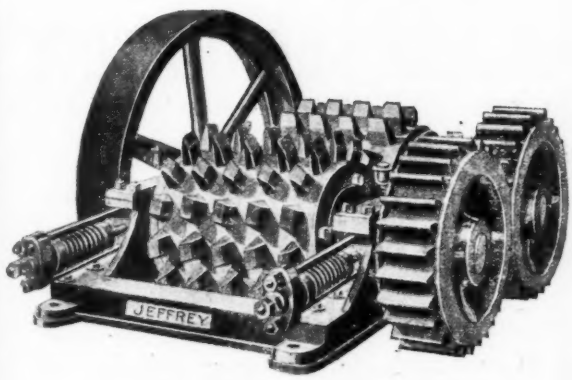


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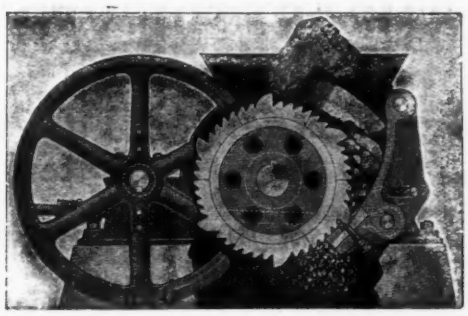

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## An ESSENTIAL ADJUNCT to

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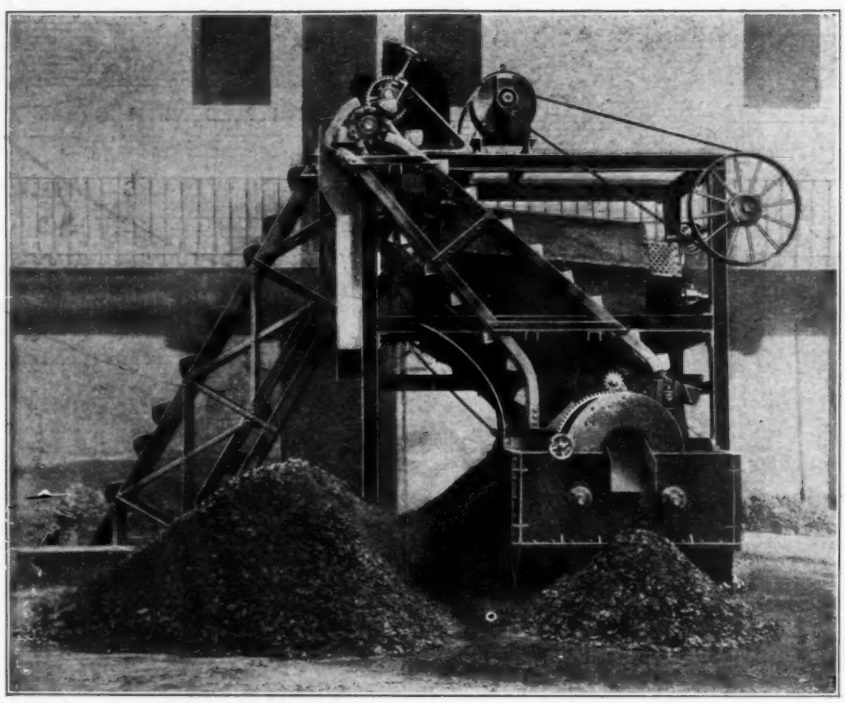

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*(Registered Trade Mark)* FOR THE *(Patent Nos. 108955/16 and 222618/23)*

**Recovery of Fuel from Pan Breeze and from Water Gas Clinkering**

*Also for* **Producing Washed Coke Breeze**

Simple, Efficient, Remunerative — Initial outlay soon recouped.
No Clay or other densifier used. — Over 50 Installations supplied.

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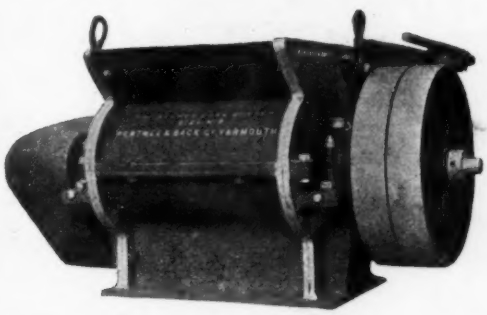

The breaking of the coke is done by chilled cast iron prickers on bars set at a correct angle for efficiency.

**These bars are renewable.**

**A minimum of breeze is produced, and a long life ensured.**

Dust-proof roller bearings used.

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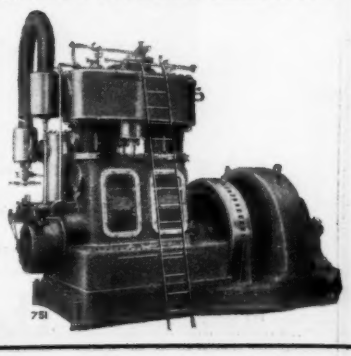
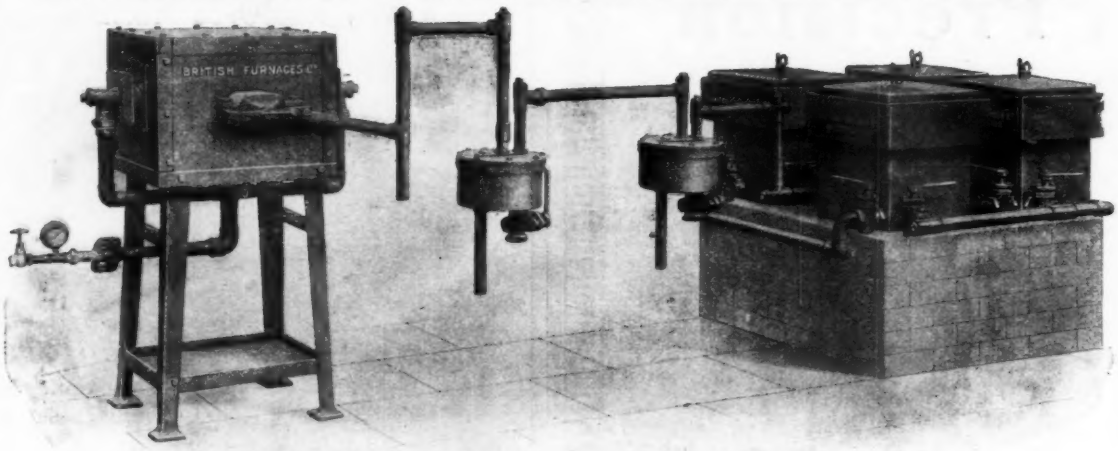


# ASSAY PLANT

FOR THE

EVALUATION OF COAL FOR CARBONISING PURPOSES

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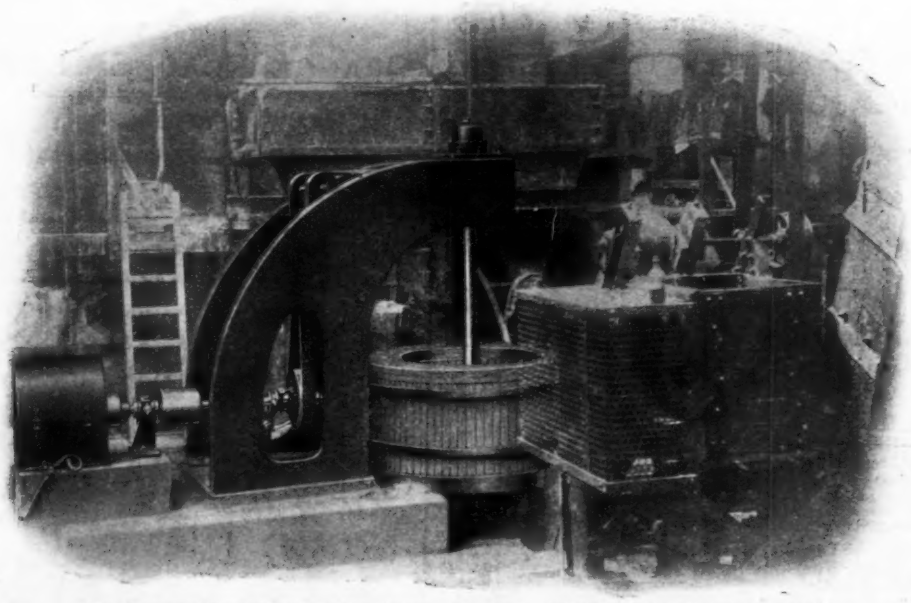

42 in. Swan-neck Type Machine driven by separate motor. (Steel Outer Case lagged with wood.)

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*The World's Best Machines for Drying Sulphate of Ammonia.*

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BASKETS made in BLACK STEEL, COPPER, or MONEL METAL.

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AT

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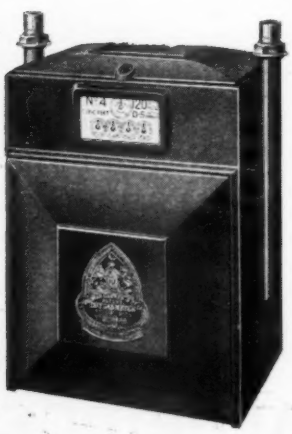

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**GOTHIC WORKS : ANGEL ROAD**

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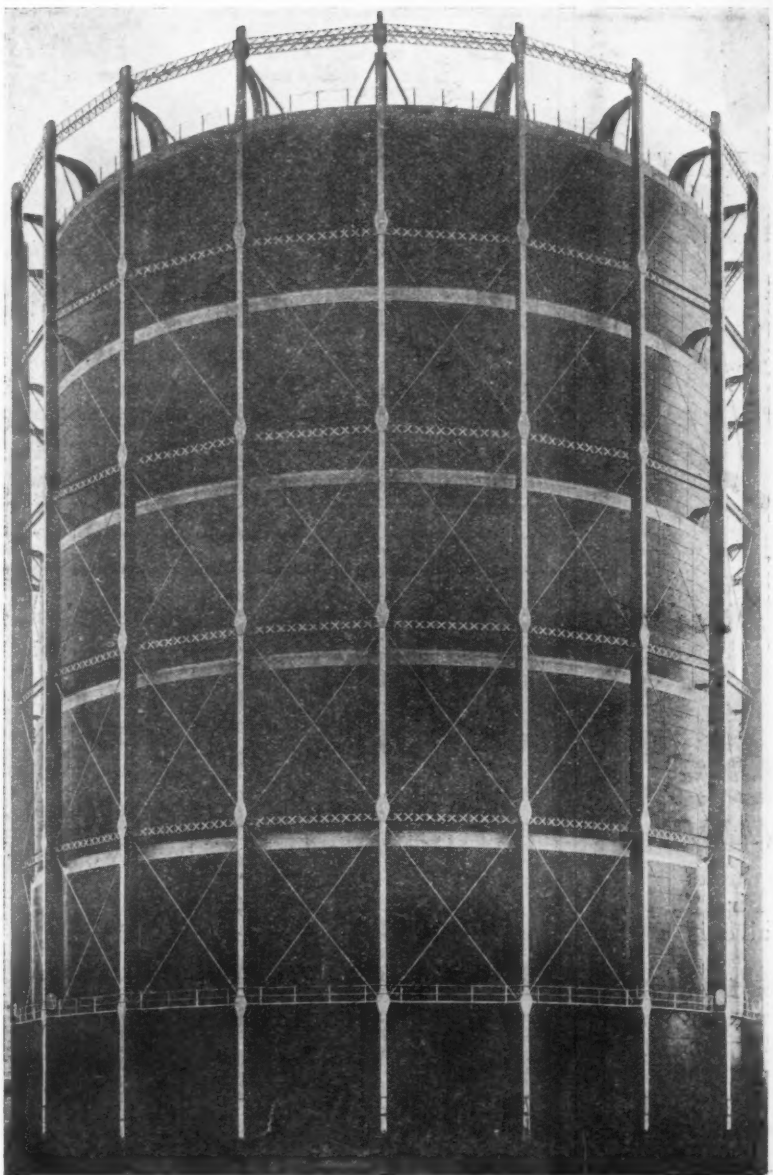

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CAST IRON &
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CAST IRON, STEEL &
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THE NEW
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CHEAPEST
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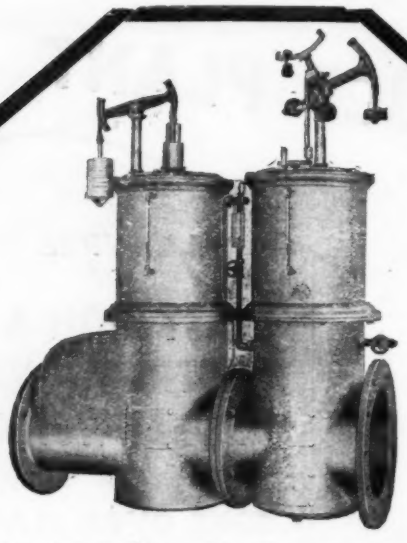
NEWTON CHAMBERS & Co LTD., THORNCLIFFE, near SHEFFIELD.



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Ask for list and names of Companies using this excellent Governor.

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**SAFETY RELIEF VALVE**

To the Gas Manager who thinks in terms of "Safety First" Peebles Safety Relief Valve is indispensable.
This automatically comes into operation when an exhauster fails, thereby preventing an abnormal rise of pressure in retorts. Install Peebles Safety Relief Valve and protect your staff and plant from explosion and fire.

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FINELY GROUND PIGMENT, WHICH IS A NATURAL MIXTURE OF TOUGH CRYSTALLINE GRAPHITE AND SILICA.

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***The proved BEST MAGNETS for Extracting TRAMP IRON from COAL***

**All kinds of Magnets for all purposes.**

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## LOW TEMPERATURE DISTILLATION OF COAL AND OIL SHALE.

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Low Operating Costs.

Large Capacity of Retorting Unit.

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Direct Production of Smokeless and Domestic Fuel.

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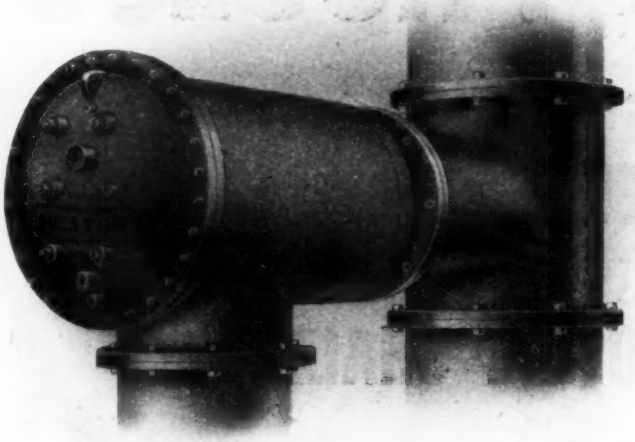
# PURIFICATION ASSISTED WITHOUT COST

***"NESTOR" GAS HEATER for raising the temperature of Gas on leaving the washers and before entering the purifiers.***
***Thus also increasing the efficiency of CONDENSATION and of WASHING***



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These Heat Interchangers are in operation at several Stations of the GAS LIGHT & COKE CO., LONDON, passing a volume of 250,000 to 300,000 c.ft. of Gas per hour—utilizing Exhaust Steam.

FOR FURTHER PARTICULARS APPLY TO THE SOLE MANUFACTURERS:— **ASHWELL & NESBIT, Ltd.** ENGINEERS AND IRONFOUNDERS

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Brick & Puddle, Mass Concrete, Reinforced Concrete.

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**Reinforced Concrete Buildings and Bridges.**

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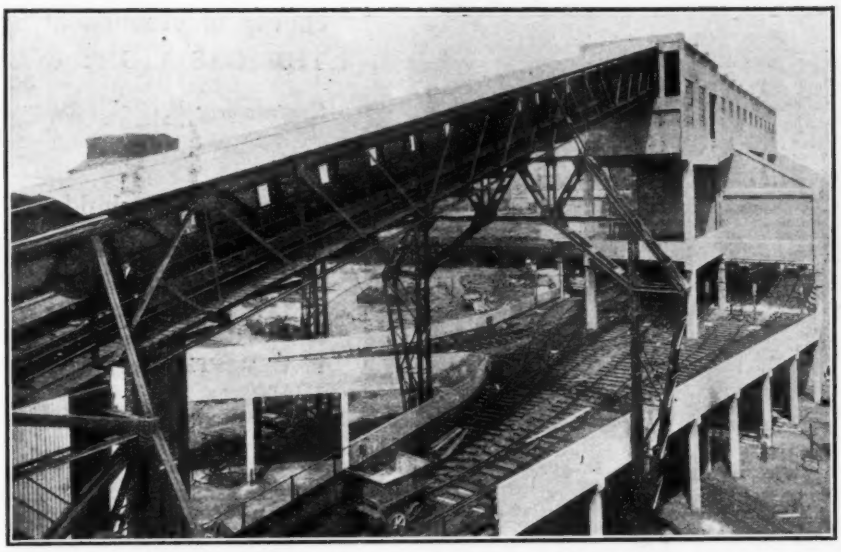
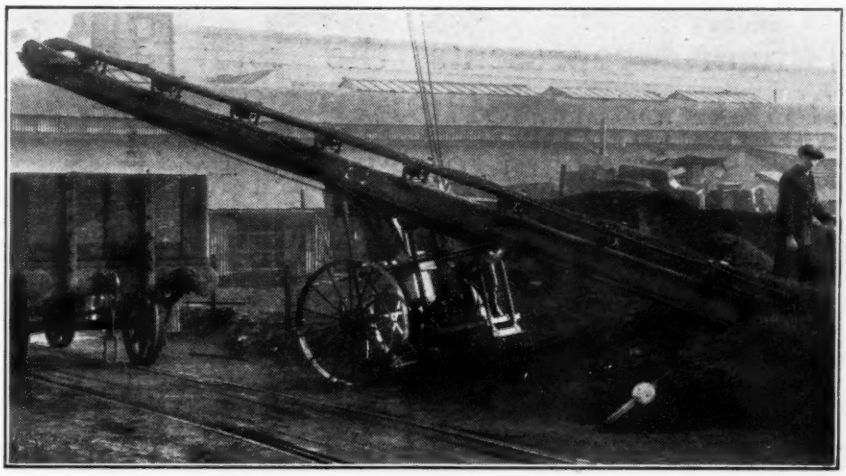


**The largest coal-handling plant in Europe.** A Fraser & Chalmers-Robins belt conveyor coal unloading plant installed in a large gas-works on the Thames for unloading coal at the rate of 2,000 tons per hour.



**A Fraser & Chalmers-Robins Standard Portable conveyor.** An ideal machine for handling stock coal. This conveyor has a 16-inch troughed belt, and is built in standard lengths of 20, 25, 30 and 35 feet. The belt carries its load without the aid of skirt boards, and handles coal, coke, ashes, etc., with equal facility. The capacity of the machine is 40 tons per hour.

The exceptionally wide experience of Fraser & Chalmers Engineering Works in the design and manufacture of handling Plants is reflected in the numerous installations, of all sizes and types, that are giving unqualified satisfaction in various parts of the world. Let us solve your handling problem. You incur no obligation by consulting us.

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WATERLESS GASHOLDER capacity 1,500,000 c. ft., now in course of erection at Staines for THE GAS LIGHT & COKE CO.

*Contractors: E. Cockey & Sons, Ltd., Frome*

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Waterless Gasholders are also being erected by our other Contractors—

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R. DEMPSTER & SONS, Ltd., ELLAND

# 338,362,000 cubic feet

This figure represents the total capacity of WATERLESS GASHOLDERS in use and on order up to January 1928.

**Of the above 15,500,000 c.ft. for Gt. Britain**

The record of the WATERLESS is a record of steady progress. The manifest advantages presented by this type of Gasholder have led to its widespread adoption.

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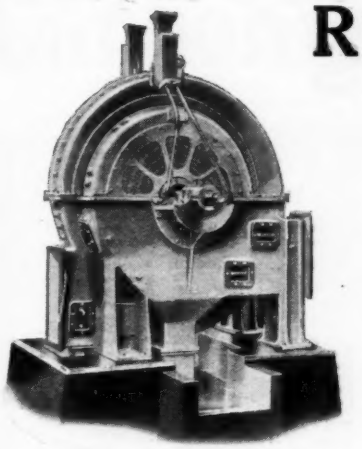
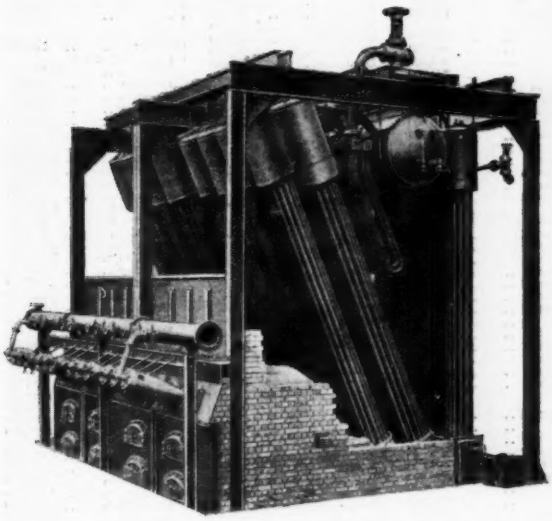
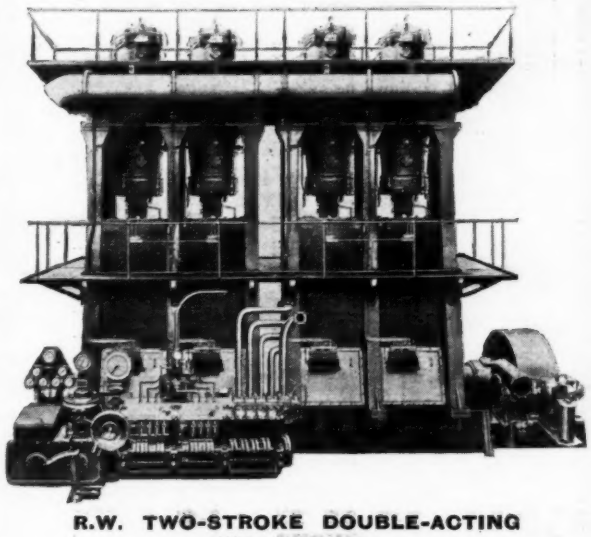
# RICHARDSONS, WESTGARTH & Co., LTD.



R.W. CROSS CURRENT GAS WASHER.



R.W. "NESDRUM" W.T. BOILER.



R.W. TWO-STROKE DOUBLE-ACTING OIL ENGINE.

**RICHARDSONS, WESTGARTH & Co., Ltd.**

*Manufacturers of*

Triple and Quadruple Expansion Marine Engines,
Double-Acting Two-Stroke Oil Engines,
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Complete Marine Installations,
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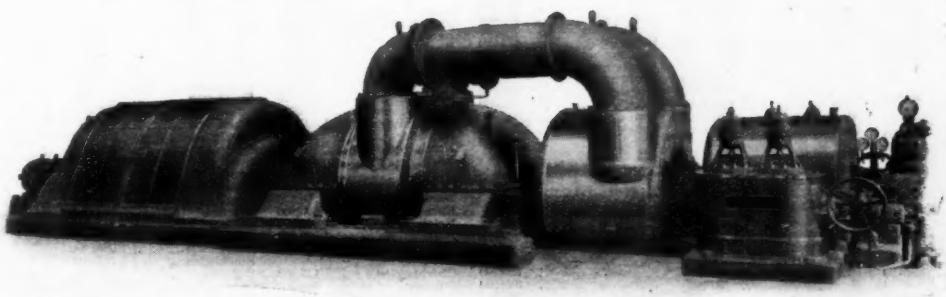
Condensing Plant, Air Extractors,
De-Aerators, Feed Heaters, Cooling Towers,
Water-Tube Boilers for Coal or Gas Firing,
Complete Power Station Equipment,
Evaporators,
Rolling Mill Engines,
Metal Mixers,
Gas Washers.

## FOUR FUEL SAVING SPECIALITIES.



RICHARDSONS WESTGARTH-BROWN BOVERI TURBINES.

# RICHARDSONS, WESTGARTH & Co., LTD.,

HEAD OFFICE: HARTLEPOOL ENGINE WORKS, HARTLEPOOL. HARTLEPOOL, MIDDLESBROUGH, SUNDERLAND. LONDON OFFICE: 121-124, ABBEY HOUSE, VICTORIA ST., LONDON, S.W.1.

# HUMPHREYS & GLASGOW, LTD.

# WATER-GAS

| | Cu. Ft. Daily |
|---|---|
| Aarhus | 800,000 |
| Abertillery | 500,000 |
| Abertillery | 100,000 |
| Admiralty: | |
| British | 800,000 |
| British | 800,000 |
| British | 800,000 |
| British | 800,000 |
| British | 800,000 |
| French | 800,000 |
| French | 800,000 |
| Agram | 200,000 |
| Airdrie | 433,000 |
| Aldershot | 1,400,000 |
| Aldershot | 1,000,000 |
| Aldershot | 1,316,000 |
| Alkmaar | 400,000 |
| Allenstein | 200,000 |
| Alost | 700,000 |
| Amersfoort | 300,000 |
| Amsterdam | 1,000,000 |
| Amsterdam | 1,000,000 |
| Amsterdam | 2,700,000 |
| Antwerp | 1,500,000 |
| Antwerp | 1,000,000 |
| Antwerp | 1,500,000 |
| Antwerp | 1,900,000 |
| Ascot | 423,000 |
| Ashford | 250,000 |
| Asnières | 650,000 |
| Augsburg | 425,000 |
| Aylesbury | 150,000 |
| Aylesbury | 470,000 |
| Banbury | 200,000 |
| Banff | 125,000 |
| Barmen | 500,000 |
| Barnsley | 588,000 |
| Barrow | 300,000 |
| Barrow | 500,000 |
| Barry | 500,000 |
| Barry | 720,000 |
| Bath | 1,000,000 |
| Bath | 1,000,000 |
| Bath | 1,300,000 |
| Belfast | 1,700,000 |
| Belfast | 4,500,000 |
| Belfast | 1,250,000 |
| Belfast | 1,250,000 |
| Belfast | 2,250,000 |
| Benrath | 125,000 |
| Berkhampstead | 259,000 |
| Berlin: | |
| Charlottenb'g | 2,500,000 |
| Danziger Str. | 1,600,000 |
| Neukoelin | 650,000 |
| Neukoelin | 700,000 |
| Schmargendorf | 763,000 |
| Tegel | 3,500,000 |
| Tegel | 6,350,000 |
| Tegel | 245,000 |
| Bideford | 258,000 |
| Bilston | 375,000 |
| Bilston | 125,000 |
| Birmingham: | |
| Adderley St. | 675,000 |
| Nechells | 3,000,000 |
| Nechells | 3,000,000 |
| Nechells | 3,000,000 |
| Swan Village | 1,500,000 |
| Windsor St. | 3,000,000 |
| Windsor St. | 3,000,000 |
| Bishop's Stortford | 200,000 |
| Bishop's Stortford | 300,000 |
| Bishop's Stortford | 200,000 |
| Blackburn | 1,190,000 |
| Blantyre | 150,000 |
| Blois | 125,000 |
| Blois | 125,000 |
| Bochum | 53,000 |
| Bognor | 100,000 |
| Bognor | 423,000 |
| Bo ness | 125,000 |
| Boulogne | 340,000 |
| Bournemouth | 1,000,000 |
| Bournemouth | 500,000 |
| Bournemouth | 1,500,000 |
| Bournemouth | 1,000,000 |
| Bournemouth | 500,000 |
| Bournemouth | 1,533,000 |
| Bournemouth | 2,000,000 |
| Bournemouth | 500,000 |
| Bournemouth | 2,750,000 |
| Bremen | 550,000 |
| Bremen | 950,000 |
| Bremen | 850,000 |
| Brentwood | 250,000 |
| Brescia | 583,000 |
| Brest | 550,000 |
| Bridgwater | 200,000 |
| Bridlington | 150,000 |
| Bridlington | 200,000 |
| Bridlington | 550,000 |
| Brieg | 100,000 |
| Brierley Hill | 250,000 |
| Brighton | 1,750,000 |
| Brighton | 1,850,000 |
| Brighton | 750,000 |
| Brighton | 2,750,000 |
| Bristol | 2,000,000 |
| Bristol | 2,500,000 |
| Bristol | 825,000 |
| Bristol | 825,000 |
| Bromley | 1,500,000 |
| Bruges | 300,000 |
| Bruges | 600,000 |
| Brussels: | |
| Anderlecht | 350,000 |
| Anderlecht | 350,000 |
| Forest | 1,000,000 |
| Forest | 1,000,000 |
| Forest | 1,000,000 |
| Forest | 1,500,000 |
| Forest | 88,000 |
| Koekelberg | 1,000,000 |
| St. Gilles | 1,000,000 |
| St. Josse | 1,000,000 |
| St. Josse | 600,000 |
| St. Josse | 775,000 |
| Ville | 750,000 |
| Ville | 750,000 |
| Ville | 1,500,000 |
| Ville | 350,000 |
| Bucarest | 1,100,000 |
| Buckie | 164,000 |
| Budapest | 50,000 |
| Budapest | 1,750,000 |
| Budapest | 200,000 |
| Budapest | 250,000 |
| Caen | 250,000 |
| Cambridge | 500,000 |
| Cambridge | 1,000,000 |
| Cardiff | 2,000,000 |
| Cardiff | 3,000,000 |
| Cardiff | 1,950,000 |
| Cardiff | 600,000 |
| Carlisle | 600,000 |
| Carlsruhe | 500,000 |
| Carnarvon | 248,000 |
| Charleroi | 1,250,000 |
| Châteauroux | 125,000 |
| Châteauroux | 125,000 |
| Châtelet | 500,000 |
| Chester | 564,000 |
| Chesterfield | 430,000 |
| Chesterfield | 90,000 |
| Chesterton | 197,000 |
| Chichester | 250,000 |
| Chorley | 300,000 |
| Cie. des Compteurs | 1,150,000 |
| Cie. Lorraine de Ch. | 210,000 |
| Cie. Mines de Roche | 585,000 |
| Coatbridge | 400,000 |
| Commercial, L'n | 850,000 |
| Commercial | 850,000 |
| Commercial | 1,250,000 |
| Commercial | 2,000,000 |
| Commercial | 800,000 |
| Commercial | 2,100,000 |
| Copenhagen | 700,000 |
| Copenhagen | 2,500,000 |
| Copenhagen | 1,750,000 |
| Courtrai | 250,000 |
| Coventry | 600,000 |
| Coventry | 600,000 |
| Coventry | 800,000 |
| Coventry | 1,250,000 |
| Coventry | 350,000 |
| Cowdenbeath | 420,000 |
| Cracow | 200,000 |
| Cracow | 200,000 |
| Cranleigh | 188,000 |
| Crefeld | 500,000 |
| Crewe | 700,000 |
| Crewe | 800,000 |
| Crosfield & Sons | 1,500,000 |
| Crosfield & Sons | 1,500,000 |
| Crowborough | 150,000 |
| Croydon | 1,250,000 |
| Croydon | 625,000 |
| Croydon | 625,000 |
| Croydon | 550,000 |
| Croydon | 650,000 |
| Croydon | 1,125,000 |
| Croydon | 150,000 |
| Croydon | 3,000,000 |
| Deal | 250,000 |
| Deal | 250,000 |
| Debreczin | 100,000 |
| Derby | 1,500,000 |
| Derby | 2,000,000 |
| Deventer | 150,000 |
| Deventer | 200,000 |
| Devonport | 1,600,000 |
| Devonport | 1,100,000 |
| Doncaster | 1,350,000 |
| Dorking | 150,000 |
| Dorking | 300,000 |
| Dorking | 130,000 |
| Dover | 500,000 |
| Dublin | 2,000,000 |
| Dublin | 2,000,000 |
| Dublin | 650,000 |
| Dudley | 600,000 |
| Dundee | 1,500,000 |
| Dunedin, N.Z. | 150,000 |
| Dunedin | 275,000 |
| Durham | 200,000 |
| Dusseldorf | 1,000,000 |
| Eastbourne | 1,250,000 |
| Eastbourne | 1,550,000 |
| Edinburgh | 2,000,000 |
| Eindhoven | 1,500,000 |
| Enschede | 282,000 |
| Epsom | 225,000 |
| Epsom | 300,000 |
| Essen | 1,400,000 |
| Essen-Borbeck | 1,400,000 |
| Exeter | 1,100,000 |
| Exmouth | 376,000 |
| Falmouth | 150,000 |
| Faversham | 200,000 |
| Flensburg | 300,000 |
| Flensburg | 125,000 |
| Forst | 300,000 |
| Frankenthal | 175,000 |
| Fuel Research Wks. | 500,000 |
| Fuel Research Wks. | 500,000 |
| Furnes | 500,000 |
| Gablonz | 140,000 |
| Gas L. & C. Co.: | |
| Beckton | 10,000,000 |
| Beckton | 7,000,000 |
| Beckton | 3,500,000 |
| Beckton | 7,000,000 |
| Beckton | 7,000,000 |
| Beckton | 5,250,000 |
| Beckton | 4,500,000 |
| Beckton | 3,000,000 |
| Bow Common | 1,000,000 |
| Bow Common | 1,150,000 |
| Bow Common | 150,000 |
| Brentford | 1,200,000 |
| Brentford | 850,000 |
| Brentford | 350,000 |
| Brentford | 750,000 |
| Bromley | 3,750,000 |
| Bromley | 2,250,000 |
| Bromley | 1,000,000 |
| Bromley | 1,000,000 |
| Bromley | 1,000,000 |
| Bromley | 1,450,000 |
| Bromley | 1,350,000 |
| Fulham | 2,500,000 |
| Fulham | 1,700,000 |
| Ilford | 650,000 |
| Ilford | 750,000 |
| Kensal Green | 2,250,000 |
| Kensal Green | 2,250,000 |
| Kensal Green | 2,250,000 |
| Nine Elms | 2,750,000 |
| Nine Elms | 750,000 |
| Nine Elms | 1,870,000 |
| Nine Elms | 2,850,000 |
| Shoreditch | 900,000 |
| Shoreditch | 2,700,000 |
| Shoreditch | 2,725,000 |
| Southall | 2,000,000 |
| Southall | 3,000,000 |
| Staines | 600,000 |
| Stratford | 1,700,000 |
| Stratford | 850,000 |
| Stratford | 2,350,000 |
| Stratford | 2,350,000 |
| Gelsenkirchen | 175,000 |
| Gelsenkirchen | 350,000 |
| Geneva | 500,000 |
| Geneva | 700,000 |
| Gennevilliers | 10,600,000 |
| Gennevilliers | 2,900,000 |
| Girvan | 235,000 |
| Glasgow | 3,000,000 |
| Glasgow | 2,500,000 |
| Glasgow | 2,250,000 |
| Glossop | 340,000 |
| Gloucester | 800,000 |
| Gloucester | 1,000,000 |
| Gosport | 200,000 |
| Gosport | 225,000 |
| Göteborg | 300,000 |
| Goteborg | 600,000 |
| Grautfenz | 200,000 |
| Grays | 250,000 |
| Grays | 400,000 |
| Groningen, Holland | 500,000 |
| Guest Keen & Piggotts, Ltd. | 1,936,000 |
| Guildford | 350,000 |
| Guildford | 200,000 |
| Guildford | 350,000 |
| Guildford | 1,100,000 |
| Guildford | 150,000 |
| Haarlem | 850,000 |
| Hamburg | 1,750,000 |
| Hampton Court | 500,000 |
| Hampton Court | 600,000 |
| Hampton Court | 1,100,000 |
| Hanley | 800,000 |
| Hanley | 800,000 |
| Hartlepool | 750,000 |
| Hartlepool | 765,000 |
| Haywards Heath | 470,000 |
| Hebden Bridge | 200,000 |
| Heidelberg | 200,000 |
| Hereford | 525,000 |
| Hertford | 197,000 |
| Hertford | 244,000 |
| Hessle | 150,000 |
| High Wycombe | 752,000 |
| Hilversum | 850,000 |
| Hinckley | 250,000 |
| Holyhead | 197,000 |
| Hong Kong | 450,000 |
| Hong Kong | 450,000 |
| Hornsey | 1,000,000 |
| Hornsey | 1,000,000 |
| Hornsey | 750,000 |
| Hornsey | 750,000 |
| Horsham | 235,000 |
| Hull | 1,500,000 |
| Hull | 1,000,000 |
| Hull | 1,600,000 |
| Innsbruck | 200,000 |
| Ipswich | 750,000 |
| Ipswich | 1,250,000 |
| Jersey | 564,000 |
| Kampen | 350,000 |
| Karlsbad | 350,000 |
| Kendal | 329,000 |
| Kidsgrove | 235,000 |
| Kiel | 1,000,000 |
| Kiel | 880,000 |
| Kilmarnock | 500,000 |
| Kilmarnock | 585,000 |
| King's Lynn | 197,000 |
| Kirkintilloch | 360,000 |
| Kirkintilloch | 827,000 |
| Kolozvar | 100,000 |
| Lancaster | 500,000 |
| Largs | 235,000 |
| Lausanne | 250,000 |
| Lausanne | 385,000 |
| Le Mans | 420,000 |
| Lea Bridge | 350,000 |
| Lea Bridge | 350,000 |
| Lea Bridge | 400,000 |
| Lea Bridge | 1,000,000 |
| Lea Bridge | 1,500,000 |
| Lea Bridge | 1,530,000 |
| Leamington | 600,000 |
| Leamington | 525,000 |
| Leatherhead | 705,000 |
| Leeds | 1,500,000 |
| Leeuwarden | 400,000 |
| Leiden | 500,000 |
| Leiden | 575,000 |
| Leigh | 350,000 |
| Lemberg | 260,000 |
| Lemberg | 500,000 |
| Letchworth | 362,000 |
| Letchworth | 423,000 |
| Liége | 1,000,000 |
| Liége | 750,000 |
| Lille | 860,000 |
| Lincoln | 500,000 |
| Lincoln | 893,000 |
| Liverpool | 3,500,000 |
| Liverpool | 4,500,000 |
| Liverpool | 750,000 |
| Liverpool | 1,750,000 |
| Liverpool | 1,250,000 |
| Liverpool | 3,000,000 |
| Liverpool | 1,500,000 |
| Liverpool | 1,250,000 |
| Liverpool | 2,350,000 |
| Long Eaton | 430,000 |
| Long Eaton | 170,000 |
| Longton | 600,000 |
| Louvain | 800,000 |
| Lubeck | 400,000 |
| Luton | 400,000 |
| Maastricht | 200,000 |
| Macclesfield | 800,000 |
| Magdeburg | 1,400,000 |
| Maidenhead | 225,000 |
| Maidenhead | 225,000 |
| Maidenhead | 175,000 |
| Maidenhead | 175,000 |
| Maidstone | 500,000 |
| Maidstone | 500,000 |
| Malines | 500,000 |
| Malines | 575,000 |
| Malmö | 350,000 |
| Malta | 400,000 |
| Manchester | 3,500,000 |
| Manchester | 3,500,000 |
| Manchester | 1,500,000 |
| Mansfield | 330,000 |
| Mansfield | 493,000 |
| Marlborough | 100,000 |
| Mayence | 700,000 |
| Melbourne | 5,000,000 |
| Merthyr Tydfil | 300,000 |
| Merthyr Tydfil | 200,000 |
| Middlesbrough | 1,250,000 |
| Middlesbrough | 750,000 |
| Middlesbrough | 900,000 |
| M/M. Woolston | 9,000,000 |
| Monaco | 375,000 |
| Monaco | 618,000 |
| Mons | 500,000 |
| Montevideo | 1,222,000 |
| Morecambe | 333,000 |
| Moscow | 1,000,000 |
| Munich | 1,400,000 |
| Namur | 175,000 |
| Narbonne | 350,000 |
| Nelson | 400,000 |
| Neuss | 140,000 |
| Newbury | 250,000 |
| Newcastle | 2,500,000 |
| Newcastle, N.S.W. | 500,000 |
| Newport Pagnell | 188,000 |
| Nice | 900,000 |
| Nictheroy | 250,000 |
| N. Middlesex | 150,000 |
| N. Middlesex | 200,000 |
| N. Middlesex | 75,000 |
| N. Middlesex | 650,000 |
| N. Middlesex | 650,000 |
| N. Middlesex | 1,000,000 |
| Northfleet | 235,000 |
| North Sydney | 500,000 |
| North Sydney | 500,000 |
| Norwich | 1,000,000 |
| Norwich | 300,000 |
| Norwich | 500,000 |
| Norwich | 1,500,000 |
| Nottingham | 1,000,000 |
| Nottingham | 1,000,000 |
| Nuneaton | 125,000 |
| Oberhausen | 175,000 |
| Oldbury | 500,000 |
| Oldenburg | 200,000 |
| Ormskirk | 170,000 |
| Ostend | 100,000 |
| Ostend | 200,000 |
| " Zandvoorde | 700,000 |
| Palermo | 968,000 |
| Palermo | 850,000 |
| Paris: | |
| Clichy | 4,000,000 |
| Ivry | 1,570,000 |
| Landy | 6,000,000 |
| Landy | 6,000,000 |
| La Villette | 4,000,000 |
| La Villette | 2,000,000 |
| St. Mandé | 1,570,000 |
| Paris-Plage | 125,000 |
| Pau | 550,000 |
| Pembroke | 240,000 |
| Perigueux | 350,000 |
| Perth, W.A. | 125,000 |
| Piggott & Co. | 1,500,000 |
| Plymouth | 2,000,000 |
| Poitiers | 350,000 |
| Pontypool | 120,000 |
| Port Elizabeth | 400,000 |
| Portsmouth | 1,000,000 |
| Portsmouth | 2,000,000 |
| Portsmouth | 800,000 |
| Portsmouth | 2,000,000 |
| Posen | 450,000 |
| Posen | 700,000 |
| Prague | 140,000 |
| Preston | 1,400,000 |
| Ramsgate | 430,000 |
| Reading | 1,000,000 |
| Reading | 1,000,000 |
| Reading | 600,000 |
| Redditch | 500,000 |
| Redhill | 275,000 |
| Redhill | 300,000 |
| Redhill | 1,100,000 |
| Reichenberg | 200,000 |
| Reichenberg | 200,000 |
| Reval | 350,000 |
| Rhymney | 175,000 |
| Rhymney | 250,000 |
| Riddings | 258,000 |
| Ripley | 120,000 |
| Rochester | 2,200,000 |
| Rochester | 2,800,000 |
| Romford | 300,000 |
| Romford | 350,000 |
| Rotterdam | 860,000 |
| Rotterdam | 1,500,000 |
| Rotterdam | 750,000 |
| Rotterdam | 750,000 |
| Rotterdam | 600,000 |
| Rotterdam | 2,000,000 |
| Royston (Yorks.) | 250,000 |
| Rugby | 1,000,000 |
| Rushden | 425,000 |
| Rushden | 517,000 |
| Saffron Walden | 235,000 |
| St. Albans | 700,000 |
| St. Andrews | 210,000 |
| St. Andrews | 409,000 |
| St. Gallen | 225,000 |
| St. Gallen | 225,000 |
| Ste. Ch.-Fr. Paroisse | 1,320,000 |
| Sté. Pr. Ch. Kuhlmann | 1,270,000 |
| Sté. Tubes Meuse | 545,000 |
| San Paulo | 700,000 |
| Scarborough | 800,000 |
| Scarborough | 200,000 |
| Scarborough | 350,000 |
| Scarborough | 1,300,000 |
| Scarborough | 1,350,000 |
| Seaford | 200,000 |
| Shanghai | 225,000 |
| Shanghai | 225,000 |
| Shanghai | 1,600,000 |
| Shanklin | 259,000 |
| Sheerness | 200,000 |
| Sheerness | 180,000 |
| Sheerness | 200,000 |
| Sheffield | 1,530,000 |
| " Steel Prods. | 5,000,000 |
| Shrewsbury | 300,000 |
| Sidmouth | 225,000 |
| Sittingbourne | 259,000 |
| Southampton | 800,000 |
| Southampton | 500,000 |
| Southampton | 600,000 |
| Southampton | 100,000 |
| Southampton | 1,000,000 |
| Southend | 1,250,000 |
| Southend | 900,000 |
| Southend | 900,000 |
| Southgate | 400,000 |
| Southgate | 500,000 |
| Southgate | 800,000 |
| Southgate | 500,000 |
| Southport | 750,000 |
| Southport | 900,000 |
| Southport | 900,000 |
| Southport | 450,000 |
| South Shields | 650,000 |
| South Shields | 1,250,000 |
| Stafford | 500,000 |
| Stettin | 880,000 |
| Stirling | 400,000 |
| Stockholm | 1,500,000 |
| Stockholm | 1,750,000 |
| Stockport | 600,000 |
| Stockport | 600,000 |
| Stockport | 400,000 |
| Stockport | 400,000 |
| Stockton | 500,000 |
| Stockton | 250,000 |
| Stourbridge | 500,000 |
| Stourbridge | 500,000 |
| Sunderland | 2,250,000 |
| Sunderland | 300,000 |
| Sutton | 1,269,000 |
| Swansea | 750,000 |
| Swansea | 1,000,000 |
| Swansea | 450,000 |
| Swansea | 1,250,000 |
| Swansea | 2,000,000 |
| Swindon | 300,000 |
| Swindon | 450,000 |
| Swindon | 400,000 |
| Sydney | 1,000,000 |
| Sydney | 1,000,000 |
| Sydney | 1,000,000 |
| Sydney | 1,000,000 |
| Sydney | 8,250,000 |
| Taunton | 225,000 |
| Taunton | 350,000 |
| Tawe Valley | 275,000 |
| Teignmouth | 200,000 |
| The Hague | 1,000,000 |
| The Hague | 500,000 |
| The Hague | 1,750,000 |
| The Hague | 1,500,000 |
| The Hague | 775,000 |
| The Hague | 1,500,000 |
| Tilburg | 400,000 |
| Tirlemont | 120,000 |
| Tokyo | 2,000,000 |
| Torquay | 350,000 |
| Torquay | 350,000 |
| Torquay | 320,000 |
| Tottenham | 750,000 |
| Tottenham | 750,000 |
| Tottenham | 350,000 |
| Tottenham | 1,000,000 |
| Tottenham | 1,000,000 |
| Tottenham | 1,250,000 |
| Tottenham | 2,500,000 |
| Tottenham | 1,000,000 |
| Tottenham | 500,000 |
| Tottenham | 1,000,000 |
| Toulouse | 1,800,000 |
| Toulouse Natl. Wks. | 2,400,000 |
| Toulouse Natl. Wks. | 6,200,000 |
| Tournai | 700,000 |
| Tours | 550,000 |
| Trowbridge | 250,000 |
| Tunbridge Wells | 1,000,000 |
| Tunbridge Wells | 1,000,000 |
| Tunis | 175,000 |
| Tynemouth | 1,100,000 |
| Tynemouth | 1,100,000 |
| Ulm | 400,000 |
| Utrecht | 1,000,000 |
| Utrecht | 1,000,000 |
| Uxbridge | 752,000 |
| Vancouver | 3,800,000 |
| Verviers | 1,000,000 |
| Vienna | 3,500,000 |
| Vienna | 2,500,000 |
| Walsall | 750,000 |
| Walsall | 875,000 |
| Waltham | 400,000 |
| Waltham | 140,000 |
| Wandsbek | 125,000 |
| Wandsworth | 1,800,000 |
| Wandsworth | 4,230,000 |
| Wanganui, N.Z. | 376,000 |
| Ware | 150,000 |
| Ware | 282,000 |
| Warwick | 125,000 |
| Wasmuel | 500,000 |
| Watford | 300,000 |
| Watford | 350,000 |
| Watford | 400,000 |
| Wath | 430,000 |
| Weimar | 100,000 |
| Wellingborough | 525,000 |
| Wellingborough | 525,000 |
| Wellington, N.Z. | 350,000 |
| West Bromwich | 550,000 |
| Westgate | 250,000 |
| Weston-Mare | 350,000 |
| Weston-Mare | 350,000 |
| Weston-Mare | 150,000 |
| Weston-Mare | 150,000 |
| Wexford | 100,000 |
| Weymouth | 400,000 |
| Weymouth | 100,000 |
| Weymouth | 658,000 |
| Whitstable | 423,000 |
| Widnes | 500,000 |
| Wiesbaden | 850,000 |
| Winchester | 225,000 |
| Winchester | 125,000 |
| Winchester | 410,000 |
| Woking | 400,000 |
| Wolverhampton | 1,500,000 |
| Wolverhampton | 1,000,000 |
| Wolverhampton | 250,000 |
| Wolverhampton | 400,000 |
| Worthing | 525,000 |
| Yarmouth | 500,000 |
| Yarmouth | 125,000 |
| Yeovil | 340,000 |
| Zwolle | 200,000 |
| Zwolle | 200,000 |
| Zwolle | 700,000 |

**842** *Sets of Humphreys-Glasgow Plant have been (and are being) installed with a capacity of over* **674,000,000** *cubic ft. of Water-Gas per diem. Including the work of their American Colleagues,* **1902** *Sets have been constructed with a total* **DAILY** *capacity of* **1,912,900,000** *cubic feet.*

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# Carbonization Conference.

## Birmingham, Feb. 21 to 24, 1928.

Organized by the Joint Fuel Committee of the Society of Chemical Industry, the Institution of Gas Engineers, the Coke Oven Managers' Association, and the Institute of Fuel.

## THE PROGRAMME.

TUESDAY, FEB. 21.—In the Small Lecture Theatre of the Birmingham and Midland Institute.

10.0 a.m. Prof. Arthur Smithells, F.R.S., the Chairman of the Joint Committee, will introduce Sir Richard Threlfall, F.R.S., Chairman of the Board of Fuel Research, who will welcome the Conference to Birmingham.

10.30 a.m. Session I. Chairman: Dr. G. C. Clayton, M.P. (Society of Chemical Industry).

The following contributions will be presented (in abstract) for discussion:

(*a*) "The Gas Industry: Past, Present, and Future." Inaugural Address of the Chairman of the London Section of the Society of Chemical Industry, Mr. W. J. A. Butterfield, M.A., F.I.C., on Oct. 3, 1927. . . 17

(*b*) *"Some Phases of Modern Practice in Gas Manufacture." By Thomas Hardie, M.Inst.C.E. . . . . 27

(*c*) †"Presidential Address to the Southern Association of Gas Engineers and Managers, 1927." By Thomas Hardie, M.Inst.C.E. . 29

(*d*) "Continuous Vertical Retorts." By Michael Barash, M.Sc. (Tech.), A.I.C., and T. Campbell Finlayson, M.Sc., A.M.I.Chem.E. . 32

(*e*) ‡"Vertical Intermittent Chamber Ovens for Gas Manufacture." By N. J. Bowater, O.B.E., B.Sc., Assoc.M.Inst.C.E. . . . 37

(*f*) "Intermittent Vertical Chambers." By R. H. Ruthven . . . . . 38

Discussion.

12.30 p.m. End of session.

2.15 p.m. Session II. Continuation of discussion on papers read during Session I.

5.0 p.m. End of session.

*"Fuel Economist," December, 1926. †"GAS JOURNAL." April 6, 1927. ‡"GAS JOURNAL," Dec. 7, 1927. The paper is also obtainable from the Institute of Fuel.

WEDNESDAY, FEB. 22.—In the Small Lecture Theatre of the Institute.

10.0 a.m. Session III. Chairman: Mr. G. A. Hebden (President, Coke Oven Managers' Association).

(*g*) "The General Scope of the Coke Oven Industry." By C. P. Finn, B.Sc., F.I.C., and R. Ray, B.Sc., A.I.C. . . . . 43

(*h*) "Modern Coke Oven Practice." By G. J. Greenfield and G. H. Harrison. . . . 45

(*j*) "Coke Research and the Steel Industry." By E. C. Evans. . . . . 51

Discussion.

WEDNESDAY, FEB. 22 (*continued*).

12.0 noon. End of session.

Those who have accepted the invitation to lunch at the Fair will leave the Midland Institute by motor at 12.20 p.m.

1.0 p.m. Lunch at the British Industries Fair by invitation of the Birmingham Chamber of Commerce and the British Industries Fair Management Committee.

5.0 p.m. Return to Birmingham by motor transport.

THURSDAY, FEB. 23.

9.45 a.m. Those who have accepted the invitation of the Birmingham Gas Committee to visit the works will meet at 9.45 a.m. at the Birmingham Gas Department, Edmund Street, and will be conveyed by motor transport to the works.

12.45 p.m. Return to Birmingham by motor.

Session IV. Chairman: Mr. J. Terrace (Vice-President, Institution of Gas Engineers).

2.30 p.m. In the Small Lecture Theatre of the Institute.

(*k*) "The Production of Blue and Carburetted Water Gas in Vertical Retorts." By T. F. E. Rhead, M.Sc., F.I.C. . . . . 59

Discussion.

(*l*) "Gas-Works Refractories." By A. T. Green, F.Inst.P. (Ass. Member). . . . . 65

Discussion.

(*m*) "Gas-Works Effluents." By A. Parker, D.Sc. 77

Discussion.

5.0 p.m. End of session.

FRIDAY, FEB. 24.—In Queen's College, Paradise Street.

10.0 a.m. Session V. Chairman: Dr. F. A. Freeth, F.R.S., F.I.C. (Institute of Fuel).

(*n*) "The Handling, Preparation, and Utilization of Gas-Works Coke." By Sir Arthur Duckham, K.C.B. . . . . 83

(*p*) "Blending in the Gas and Coke Oven Industries." By John Roberts, D.I.C. . . . 85

Discussion.

12.30 p.m. End of session.

Session VI.

2.15 p.m. (*q*) "A General Review of Low-Temperature Carbonization." By F. S. Sinnatt, M.Sc., F.I.C. . . 90

(Contributions to the discussion are expected from technical staffs, connected with processes of low-temperature carbonization, who have been invited to attend.)

5.0 p.m. End of session.

**THE Publishers announce that a report of the discussions which take place at the Conference will be published in the "GAS JOURNAL." For those who desire a self-contained record of the whole proceedings, reprints of the discussions will be available at 2/6 per copy—in form suitable for insertion into this book. A strictly limited number of copies of papers and discussions bound in the paper cover will also be on sale at 5/- each. Early application should be made to—**

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W-D

# CARBONISATION

The problems facing the Gas Engineer of to-day are infinitely greater than those of 30 years ago. With the speeding up in industry and the necessity for reducing costs of production all round, there have been enormous developments in the methods employed in the production of Town's Gas.

The question which each Gas Engineer puts to himself, when having to make his plans for increased production or for renewals of plant, is "What type of carbonising plant will enable me to reduce the cost of production of gas under my particular local conditions of coal supplies and markets for my products?"

Very few undertakings are alike in this respect, and it is not practicable to standardise the requirements of Gas Engineers.

Undertakings situated long distances from the sources of coal supply frequently find it pays to buy the highest qualities and the best grades.

Other undertakings closely situated to the Pit Mouth can, with advantage, buy lower grades of cheap coals—very often slacks—which it would not pay to carry long distances.

Some undertakings have a ready outlet for all the coke they can produce; others, because of local conditions, find great difficulty in selling their full make.

Under these conditions, it is essential that Engineers should have at their disposal a selection of Carbonising Systems which will enable them to choose the one which will best satisfy their requirements.

In one case it may be CONTINUOUSLY WORKING VERTICAL RETORTS, which give a high thermal yield per ton of coal and per unit of ground space, combined with a first-class Domestic Coke and low Labour costs per therm made.

On the other hand, INTERMITTENT VERTICAL CHAMBERS may suit the conditions of a smaller works best. In these plants it is possible to use any class of coal, particularly cheap slacks, and produce a dense coke suitable for domestic purposes when properly screened, but more suitable than Continuous Vertical Coke for industrial furnace work. These plants occupy much less ground space than Horizontal Retorts, require less labour, and will give a satisfactory thermal yield per ton of coal.

On larger works, the conditions holding for Intermittent Verticals may, with advantage, be obtained from either INCLINED CHAMBERS or from COKE OVENS of such sizes and dimensions as will best suit the size of works on which they are installed. Chamber Ovens occupy less ground space than Coke Ovens, but in every respect are similar in the results they will give.

The Woodall-Duckham Companies are in a position to supply any of these systems, and so meet the particular requirements of the individual Gas Engineer. Impartial advice can be given by Technicians having an invaluable experience of all Carbonising Systems, this experience being backed up by sound design, materials of the highest quality, and a Constructional Organisation capable of handling any demands that may be made upon it.

*Reprinted from the Illustrated Descriptive Supplement to "Britain's Fuel Problems."*

The WOODALL-DUCKHAM VERTICAL RETORT & OVEN CONSTRUCTION CO.,(1920) LTD.

## SESSION I.—Chairman : Dr. G. C. CLAYTON, M.P. (Society of Chemical Industry).

**Paper A.**

# The Gas Industry : Past, Present, and Future.

## Public Utility Services.

**Inaugural Address of the Chairman of the London Section of the Society of Chemical Industry, Mr. W. J. A. BUTTERFIELD, M.A., F.I.C., delivered at a Meeting on Oct. 3, 1927.**

The chief public service, or public utility, industries, apart from those carried on by departments of the State, are transport, and water, gas, and electricity supply.

Water supply is a simple adaptation of natural resources to the necessities of dwellers in communities, and dates from early historical times. Primarily a branch of hydraulic engineering, it now embraces problems of chemical treatment, but not of chemical industry proper. For domestic needs, at least, it is not subject to competition; and a reduction of consumption is often a laudable ambition, since it connotes elimination of waste. In these respects water supply stands apart.

Transport as an organized public service is a much more recent development, but in its various ramifications of railways, tramways, and omnibus is that on which there has been the largest capital outlay, and which has the largest revenue of the public utility services. It has developed from organized systems of horse vehicles, traversing certain routes at known times, and available at equal charges for equal service to any member of the public, to the present stage in which power derived from fuel or a head of water has almost entirely displaced the draught animal. It embraces problems of practically all branches of engineering, but is in no sense a chemical industry, though naturally chemical problems indirectly arise in connection with it. The application of mechanical power to propulsion on railways, tramways, and waterways is of somewhat later date than the inception of public gas supply.

Electricity supply is the smallest of the public utility services, and, being also the youngest member of the family, receives more favours than its elder brethren. Tit-bits by way of special financial facilities are bestowed upon it, while maternal (and grandmaternal) caresses are lavished on it in season and out of season by its self-constituted sponsors in Parliament and the Press. Whether, as it attains puberty, it will be the better for these favours remains to be seen, but we all remember that a spoilt child is apt to become in later life a costly burden on the community. Electricity supply is in no sense a chemical industry.

The gas industry, as a public service, had its beginnings in 1812, on April 30 of which year the Gas Light and Coke Company received its Charter of Incorporation, which was granted under an Act passed in 1810. By the year 1815, this Company had fifteen miles of street mains, extending in one area from Norton Folgate to the west end of Cheapside, and in another area from Pall Mall and Westminster to Temple Bar. Another Company at that time had gas mains from Temple Bar to the west end of Cheapside, while other companies were being formed to supply Southwark and the east end of London.

It is thus now 115 years since the birth of gas supply as a public service, and its growth has been fairly uniform and vigorous right up to the present time, while the prospects of expansion for many years to come are extremely rosy. Members of this Society will regard the progress of the gas industry with no little satisfaction, because gas supply is the only public utility service which is fundamentally a chemical industry.

In the magnitude of the services it renders to the public, it is second only to the railway organization. From Table I. it will be seen that the revenue of the gas undertakings of Great Britain is one-third to one-half the revenue of the railways, and half as much again as that of the electricity undertakings. The profit shows a moderate return of about 6 p.ct. on the outstanding capital in the gas industry, whereas at the present time the corresponding figures are about 3 p.ct. for the railways and over 9 p.ct. for electricity undertakings. It would therefore seem that, of these three great public utility services, the gas industry makes less call on the capital resources of the country, relatively to the service it renders, than either railways or electricity supply. The figures given cover gas and electricity undertakings having statutory powers, including those owned by local authorities; but as regards electricity, the latest available information does not cover any part of the disastrous coal stoppage. Four-elevenths of the gas sold in Great Britain is supplied by local authorities, whereas about seven-elevenths of the electricity supplied is generated at works belonging to local authorities. It would be outside the scope of this address to attempt to trace any connection between these varying degrees of public ownership and the profits shown in the table.

### EARLY YEARS OF GAS SUPPLY.

The early years of public gas supply were eventful in many respects; and having regard to the novelty of the work, and the prejudices it aroused—not least among scientific men—it is really surprising that progress was so rapid. From the outset, the managers of gas-works appear to have determined that there should be no interruption, through accident or otherwise, of the supply, and a map [which was reproduced as fig. 1 when the paper was reprinted in the "GAS JOURNAL" for Oct. 26 last] of the street mains in the

TABLE I. (*Revised*).—*Capital, Receipts, and Profits of Statutory Public Utility Services* (1925-26), *Great Britain.*

| Undertakings | Railways (Railway Working Only). | | Gas. | | Electricity. | |
|---|---|---|---|---|---|---|
| Year | 1925. | 1926. | 1915. | 1926. | 12 Months to 31st March, 1925. | 12 Months to 31st March, 1926. |
| Capital outstanding, £ | (Actual) 1,060,525,503 | (Approx.) 1,067,100,000 | (Actual) 138,561,659 | (Actual) 143,954,144 | (Actual) 194,019,658 | (Approx.) 217,038,306 |
| Receipts, £ | 199,652,875 | 171,800,000 | 66,042,643 | 74,701,868 | 40,914,276 | Not out |
| Profits (gross), £ | 34,628,863 | 17,800,000 | 9,133,995 | 7,729,121 | 18,428,865 | 19,663,670 |
| Ratio of receipts to capital, p.ct. | 18·82 | 16·10 | 47·66 | 51·89 | 21·09 | .. |
| Ratio of profits to capital, p.ct. | 3·26 | 1·66 | 6·59 | 5·36 | 9·50 | 9·06 |

vicinity of Charing Cross, given in Accum's "Treatise on Gas-Light," published in 1815, shows that they were interconnected in such a manner that one works might take up any temporary curtailment or failure of supply from another works, and that even a fractured main would not cause more than purely local interruption of supply.

### GAS—THE ONE PUBLIC SERVICE WHICH NEVER FAILS.

The tradition, shown to have been well established within three years of the inception of public gas supply, that the service must be maintained at all costs, has ever since been rigorously observed by the gas industry. No other public utility service has a record which stands comparison in that respect with it.

Water supply, even at the present day, is subject in many areas to limitation to a few hours a day in seasons of prolonged drought. Railway services are curtailed or fail completely locally, and occasionally generally, through their own staff, or the coal miners, ceasing work; omnibus services fail on similar grounds; tramways and underground railways stop for the same reason, and in addition all too frequently because of breakdowns in the electricity generating and distributing plant. Public electricity supplies are cut-off at times by reason of withdrawal of labour, and frequently fail for longer or shorter periods either over an extensive area, or quite locally, through short-circuits or "blowing" of fuses.

### GAS SUPPLY DURING THE TURMOIL OF 1926.

An intimate acquaintance with conditions in the gas industry for more than 35 years past warrants the statement that, in that period at least, there has been no serious interruption of gas supply in any place worthy of its name in Great Britain. The culmination of the industry's career in this respect was reached during the period of the general strike and coal stoppage last year, when every other public utility service (water supply perhaps excepted) failed for longer or shorter periods in important areas, if not everywhere. It will always redound to the credit of the gas industry that it alone of the great public utility services was prepared to face all the contingencies of those trying and eventful months.

For some years past, most gas undertakings had kept in hand, throughout the year, stocks of coal and oil sufficient for at least two months' requirements—often considerably more. During last year's stoppage of normal supplies, these sufficed until foreign coal and more oil could be purchased and delivery obtained. But even more than for preparedness in the matter of its raw materials is the gas industry to be commended for the harmony and loyalty which it had inspired in all ranks and grades of its staffs, as a consequence of which for some days practically the only industrial premises in many districts in which managers and men pursued their daily tasks in a normal manner were the gas-works.

For this devotion to duty on the part of the rank and file of the gasworkers, acknowledgment is due in large measure to the wide adoption by gas undertakings of co-partnership schemes. The institution of co-partnership by Sir George Livesey in the South Metropolitan Gas Company took place some 37 years ago. One of the Past-Presidents of this Society, Dr. Charles Carpenter, M.B.E., assisted at its birth, and he has since been indefatigable in commending it to other gas undertakings, a large number of which have adopted it. Comparatively few other industrial concerns, however, had adopted it prior to May 3, 1926, and the rest then found themselves faced with labour troubles from which the gas industry remained practically immune.

The failure of all their ordinary sources of supply of coal eventually, however, prevented a portion of the gas undertakings strictly fulfilling their normal obligations to the public, especially as, with the growing scarcity of household coal, the demand for gas increased considerably in many districts. The choice lay between restricting the volume of gas passed into the distributing system and reducing the calorific value. The first alternative would have meant that consumers in some parts of the district would have had nearly all the available gas, and consumers in other parts would have been able to get very little. The second and more equitable alternative was naturally that chosen, in practically every district in which a full supply of gas of the normal calorific value could not be maintained.

It must not be supposed, however, that there were widespread or serious deviations from the normal course of gas supply. Table II. shows succinctly the

**TABLE II.—1926. *Effect of Coal Emergency Conditions on Gas Supply in Great Britain.***

General Strike started May 3, 1926. Coal Dispute ended Nov. 30, 1926.

Coal Emergency Regulations issued by Board of Trade in force from May 1 to Dec. 19, 1926.

Proportion of gas sold on which testings under Gas Regulation Act should have been made in 1926 (4th quarter) . . . . . 80·3 p.ct.

Proportion of gas sold on which testings under Gas Regulation Act were made in 1926 (4th quarter) . 71·5 ,,

Proportion of gas tested in which—
(1) The declared calorific value was fully maintained.
(2) The deficiency was *nil*, or less than 5 p.ct.

| 1926. | Declared Calorific Value Fully Maintained. | Deficiency *Nil*, or Less than 5 P.Ct. |
|---|---|---|
| | P.Ct. | P.Ct. |
| First quarter . . . . . | 99·99 | *Nil* |
| Second quarter . . . . . | 73 54 | 99·14 |
| Third quarter . . . . . | 71 17 | 89·93 |
| Fourth quarter . . . . . | 77 58 | 92 44 |

manner in which, to use a Biblical metaphor, the gas industry succeeded in making bricks—and good bricks too—without straw, when those who should have provided it with its counterpart of the latter lamentably failed it.

It will be seen from the table that only about 80·3 p.ct. of the gas sold in Great Britain was liable at that time to be tested under the provisions of the Gas Regulation Act; and as regards 8·8 out of this 80·3 p.ct. the local authorities and consumers affected had failed to take the necessary steps to ascertain the calorific value of the gas delivered. But there is definite information from the independent official gas examiners as to the calorific value of about 71·5 p.ct. of the gas supplied by authorized gas undertakers in Great Britain throughout the general strike and coal stoppage of 1926. It will be seen that, as regards over 70 p.ct. of the gas which was thus tested, the declared calorific value was maintained unimpaired throughout that time. As regards another 20 p.ct., the average deficiency in calorific value in any quarter was less than 5 p.ct. Thus we see that, as regards those gas undertakings whose supplies were officially tested—representing 71·5 p.ct. of the gas sold in Great Britain—only 10 p.ct. of the gas which they sold in any quarter of that troublous year was more than 5 p.ct. lower in average calorific value than it would have been in normal times.

It must be a matter of congratulation to members of this Society that the one public utility service which is fundamentally a chemical industry comported itself so well as these figures indicate throughout the industrial turmoil of 1926. It is difficult to envisage the hardship and misery which would have ensued in our larger towns, especially to the weaker members of the community, had the gas supply failed even for a day.

### PRESENT CONDITIONS OF GAS SUPPLY.

Having glanced at the past, and having indicated also the superior standing of gas supply among the public services in the matter of trustworthiness in all circumstances, it will be convenient now to refer to the present condition of the gas industry.

Next to continuity of supply, the present aim of gas undertakings is to deliver gas which does not vary greatly, from day to day and from hour to hour, in its calorific value. This aim has received legislative authority through the provisions of the Gas Regulation Act, which came into force on Jan. 1, 1921. A gas undertaking is, however, brought under its provisions only when an Order therefor is made by the Board of Trade.

The testing provisions of the Act became applicable to more than 100 gas undertakings during the latter part of 1922. It is instructive to observe from that year onward the extent to which the undertakings whose supply has been tested in accordance with the prescriptions of the Gas Referees, who are appointed under the Act, have fulfilled the obligations to supply gas of which the average calorific value in any quarter, ascertained from those testings, is not less than the declared value of the undertakers. In any quarter in which the ascertained average calorific value is less than the value which the undertakers have declared they will supply, which value is the basis of charge by the therm, the Chief Gas Examiner determines the amount by which the revenue of the undertakers has consequently been improperly increased. Such amount has to be applied to a reduction in the price of gas

in a subsequent quarter. In practice, the Chief Gas Examiner determines the improper increase in revenue as a proportion of the gas rental for the quarter, corresponding with the ratio of the deficiency in average calorific value to the declared calorific value. The ultimate effect of his determination is, therefore, that consumers as a whole pay on the basis only of therms actually received in any quarter in which the average calorific value has been ascertained to be less than the declared value. The adjustment is necessarily deferred to a subsequent quarter; but the trouble of having to make it, and the opprobrium attaching thereto, are such that none of the larger gas undertakings, even might they have been so minded, have risked any infraction of their obligation in this respect. These remarks must not be taken as suggesting that moral responsibility is not the predominant force which determines the observance of obligations by the majority of the gas undertakers in this country.

Lapses have, however, occurred in certain instances since the fourth quarter of 1922, and the proportion of such cases is shown in fig. 2, as a percentage of the number of undertakings whose gas supply was officially tested in each quarter. These numbers range from 111 undertakings in the fourth quarter of 1922, to 383 undertakings in the second quarter of 1927. The percentages of lapses in one or two quarters may appear large; but it must be emphasized that the proportion of all the gas sold which is affected by these determinations is almost negligible. In no quarter did the gas to which these determinations applied represent more than 750 c.ft. out of every million c.ft. of gas in respect of which official testings were made; and the mean deficiency in calorific value for all the cases was only 1·25 p.ct. Fig. 2 shows also that, in several quarters, no undertaking whose gas was tested had an average below its declared calorific value.

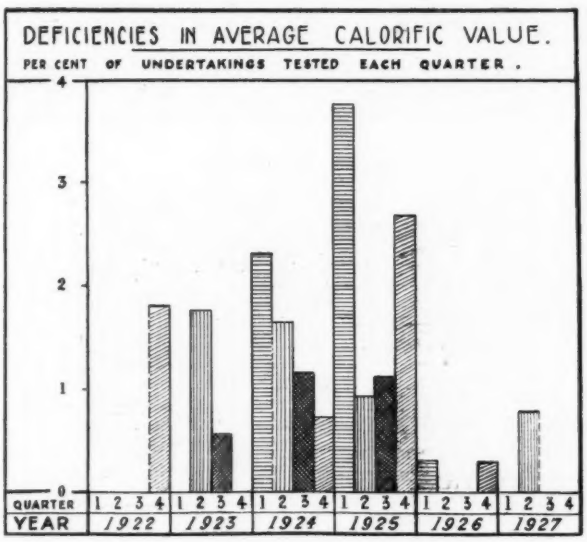

DEFICIENCIES IN AVERAGE CALORIFIC VALUE.
PER CENT OF UNDERTAKINGS TESTED EACH QUARTER.
4
3
2
1
0
QUARTER 1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4
YEAR 1922 1923 1924 1925 1926 1927

Fig. 2.—Diagram of Deficiencies.

It might, therefore, be argued that any adjustment of charges is unnecessary, and not worth the trouble entailed thereby; but against this must be set the good influence the principle involved has upon the relationship between the gas undertaker and the gas consumer. The latter feels that he is protected against being charged for gas of higher quality than that which he has in fact received. The principle of adjustment referred to was introduced in the Gas Regulation Act, 1920, largely, it is understood, at the suggestion of Mr. H. C. Honey, O.B.E., who became under the Act the first Director of Gas Administration at the Board of Trade.

### The Therm System of Charging.

The system of charging for gas supplied by the therm in place of by simple volume, was introduced through the Gas Regulation Act; and for its adoption and retention three Past-Presidents of this Society have been largely responsible. Dr. Charles Carpenter, M.B.E., impressed its value upon the Fuel Research Board, who, in 1919, under the chairmanship of Sir George Beilby, F.R.S., recommended its adoption. In 1923, a Departmental Committee, of which Mr. W. J. U. Woolcock, C.B.E., was a member, reported: "We are unanimously of the opinion that the method of charging for gas on the basis of its heating properties—*i.e.*, by the therm—is the best safeguard of the consumer." Having regard to the fact that, under the therm system, the consumer does not pay for whatever incombustible constituents there may be in the gas, it is not surprising that one of the aims in a modern gas-works is to keep the proportion of such components as low as is consistent with a high degree of uniformity in calorific value and density.

It is hardly necessary to explain the therm system at the present time; but it may perhaps be said briefly that a therm is 100,000 British thermal units, and the number of therms consumed is ascertained by multiplying the number of cubic feet of gas, as registered by the consumer's meter, by the number of British thermal units which the gas undertaking has declared that 1 c.ft. of the gas supplied by it will contain, and dividing the figure so found by 100,000. For example, if the declared calorific value is 600 B.Th.U. per c.ft., 1000 c.ft. of the gas afford 6 therms; whereas if the declared value is 200 B.Th.U. per c.ft., 1000 c.ft. afford only 2 therms. These figures of 600 and 200 do, in fact, represent the extreme limits of calorific values declared by any undertakings in Great Britain; but probably 90 p.ct. of the gas supplied in this country falls between 440 and 560 B.Th.U. per c.ft.

Gas undertakings have been given freedom of choice in order that they may adopt such a calorific value as is obtainable economically from the coal and oil locally available, and is adapted to the special needs of the district. The only direction in which the freedom of choice given to undertakers as to the calorific value of the gas they supply can become detrimental to the interests of the consumer is that apparatus is not, without re-adjustment, transferable from one district to another in which the calorific value differs therefrom by as much as 50 B.Th.U. per c.ft. This particularly affects bodies such as the railway companies, which have premises in many different districts and desire, as far as possible, to use similar standard gas appliances throughout.

Therms in the gas accounts rendered to consumers are based on the declared calorific value of the gas. Since the average calorific value for any quarter, as ascertained from the official testings, must not be less than the declared value, the gas supplied to the consumer in practice is of somewhat higher average value than the declared value.

### Uniformity in Calorific Value.

There is the further requirement in the Act that the gas shall not for any period of two hours remain as much as a full 6 p.ct. below the declared value. This requirement tends to promote uniformity in the calorific value of the gas received by the consumer. This uniformity is, in general, more marked in the supplies given by large than by small undertakings; but some of the latter achieve practically as good results as the former.

By way of indicating the uniformity of calorific value of the supply given through two trunk mains, each of not less than 30 in. diameter, reproductions are given for one week in each case (figs. 3 and 4) of the record sheets of recording calorimeters in use in official testings of the gas supplied by the undertakers in question. The length of record sheet is 6 in. for a period of 24 hours, and the fluctuations of calorific value are shown on a scale of half-an-inch for 5 p.ct. It will be seen from figs. 3 and 4 that the gas very rarely deviates as much as 3 p.ct. from the average calorific value. The figures written on the sheets have been put in by the County Gas Examiner at the end of the week, and illustrate the manner in which he deduces, or integrates, from the line, after certain corrections have, if needed, been made for deviation from the results of control testings, the mean calorific value for each period of six hours, and thence for the day and for the week.

**Table III.**—*Extent of Variation in Calorific Value of Gas Supplied by Six Large Undertakings in the First Quarter of 1926.*

[From results of two testings each day at one of the testing places for each undertaking.]

Declared Value = 100.

| Undertakers . . . . | A. | B. | C. | D. | E. | F. |
|---|---|---|---|---|---|---|
| Average ascertained . | 100·62 | 101·70 | 100·18 | 100·24 | 100·80 | 100·65 |
| Highest result . . . | 102·20 | 103·20 | 102·44 | 103·30 | 105·05 | 106·25 |
| Lowest result . . . | 98·23 | 99·00 | 96·86 | 97·10 | 97·58 | 97·13 |
| Extreme difference . | 3·97 | 4·20 | 5·58 | 6·20 | 7·47 | 9·12 |

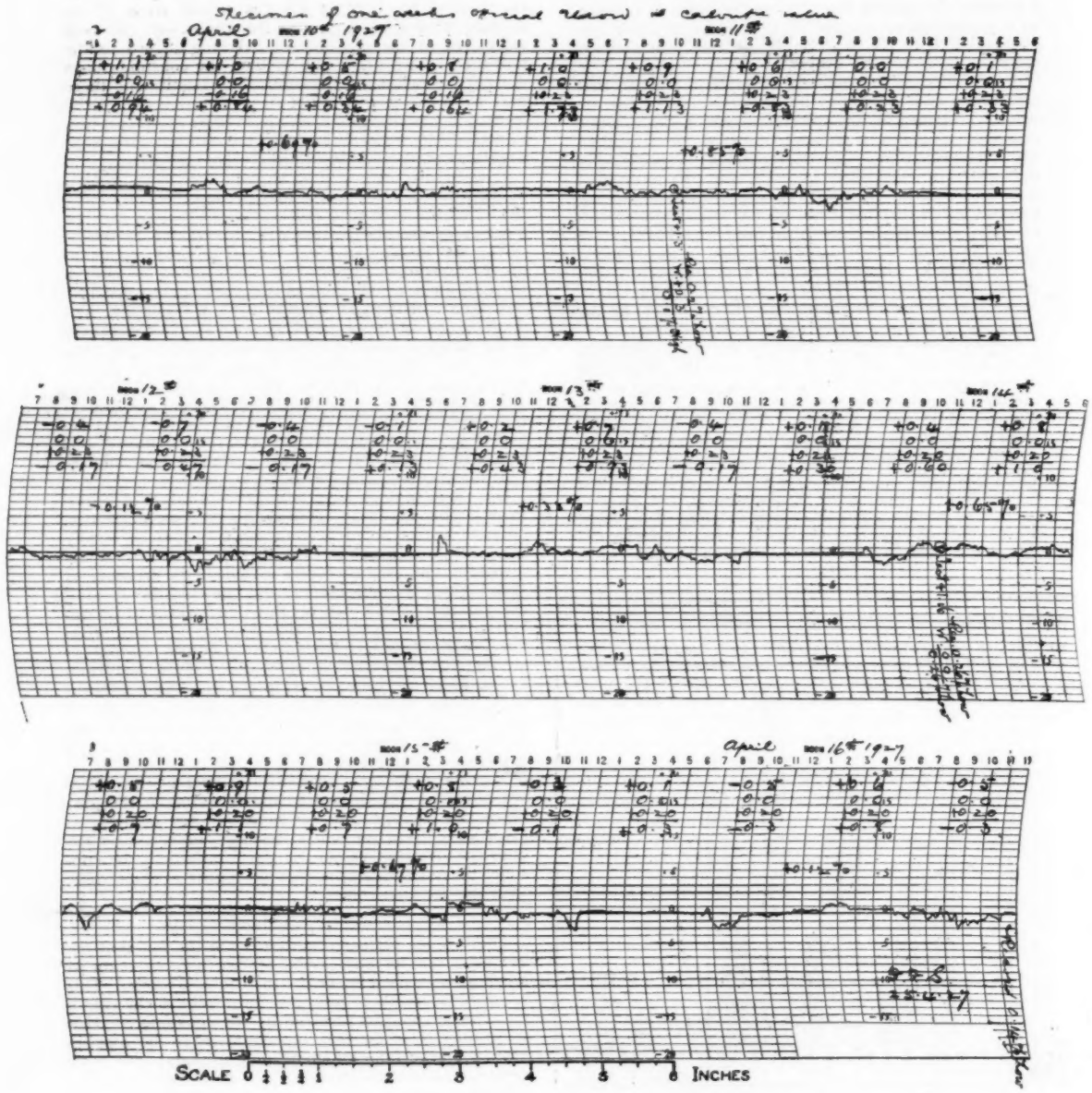



FIG. 3.—ONE WEEK'S OFFICIAL RECORD OF CALORIFIC VALUE.

These record sheets each cover only one week, but may be taken as typical in each case of the records for the supplies to which they refer. In many other instances, two testings are made each day with a non-recording calorimeter, and Table III. shows for six testing places, each on one of the trunk distributing mains of a different undertaking, the range of variation of the results of the testings for a complete quarter. The first quarter of 1926 has been chosen as the last winter quarter in which the coal carbonized was wholly from normal sources of supply. It will be seen that the percentage deviations from the average are not great, though obviously some of the supplies happened in that quarter to be much better than others in this respect.

All these figures refer to large undertakings, each selling over 3000 million c.ft. of gas per annum, and most of them accustomed to control, to some extent at least, by testings of calorific value made by independent gas examiners, for some years before the Gas Regulation Act came into force. Many undertakings, especially those of medium and small size, had not previously had the calorific value of the gas they supplied controlled by independent testings; and it was by reason of the novelty to them of such control that some failed to take the necessary steps to meet without fail the requirements of the testing provisions of the Act. The lapses revealed by the diagram already given (fig. 2) no doubt were largely brought about through ignorance of the undertakers as to the actual calorific value of the gas they were supplying, and the declaration by them of a higher calorific value than they could in fact maintain. Also, their gas was subject to relatively large fluctuations in calorific value. The diagram already given, and the detailed records of official testings since 1922, indicate that many small undertakings whose gas varied greatly in calorific value a few years ago are now supplying gas which is much more uniform in value, and is therefore adapted to give a greatly improved service and better satisfaction to the consumer. In this respect, the application of the testing provisions of the Gas Regulation Act to comparatively small gas undertakings appears to have been justified by the improvement which has ensued in the uniformity of the gas they supply.

### THE TREND OF DEVELOPMENTS.

The two primary conditions of continuity of supply and uniformity of calorific value having been discussed, the trend of developments in gas-works operations, and in the distribution and use of gas, may be briefly reviewed.

Recent years have witnessed the gradual introduction of great changes in gas manufacturing processes, of which perhaps the most fundamental is the carbonization of coal in retorts or chambers into one end of which it is delivered continuously, or in small instalments, while the coke is similarly withdrawn from the other end. The intermittent charging and complete emptying of retorts has almost disappeared from many of the larger works, and therewith has gone the one gas-works operation which was apt to be pro-

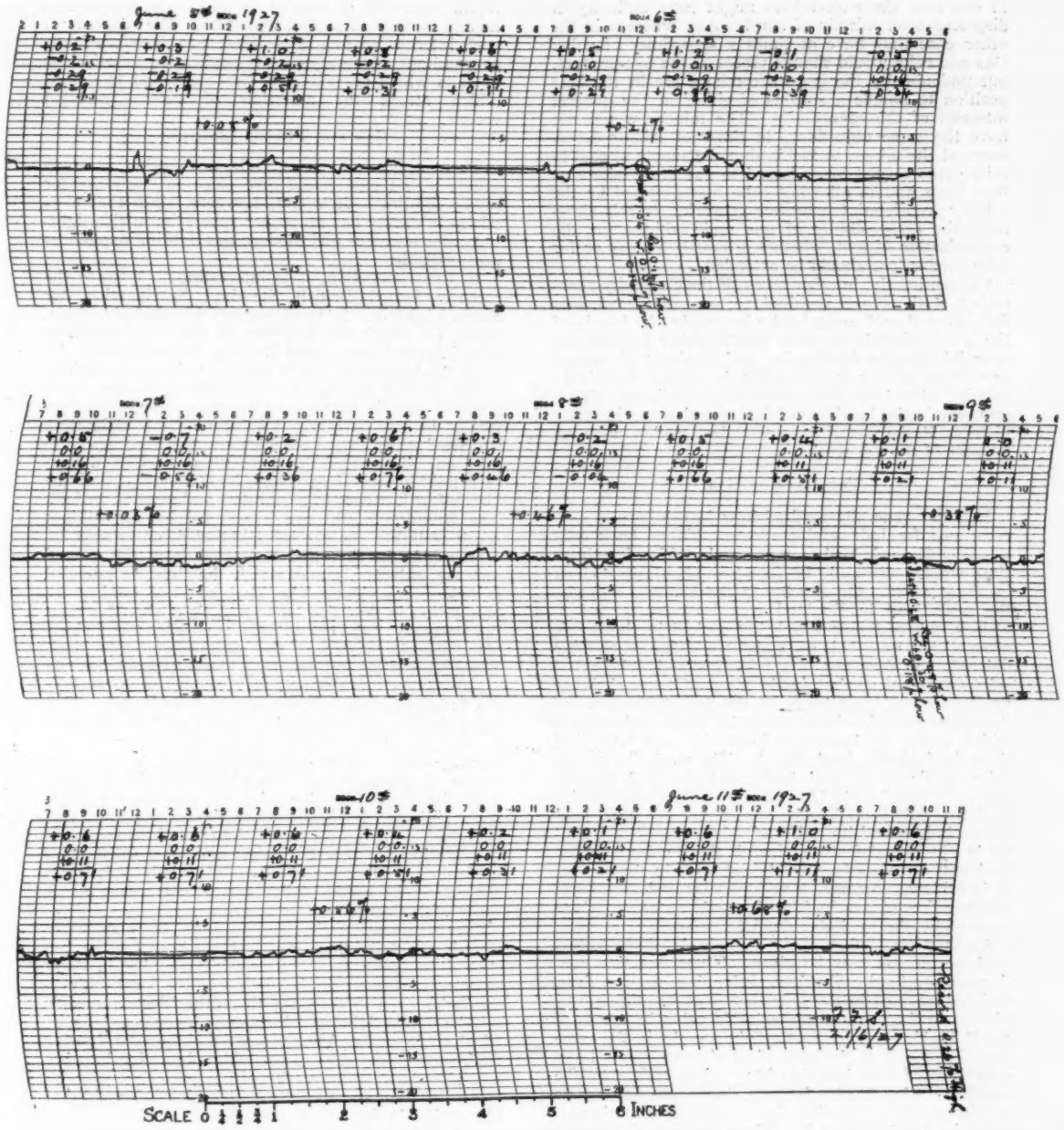



FIG. 4.—ONE WEEK'S OFFICIAL RECORD FROM ANOTHER INSTRUMENT AND SUPPLY.

ductive of smoke. The modern gas-works, in the matter of smoke and dust, compares extremely favourably with any industrial works of similar magnitude. In particular it contributes much less to the smoke pall over our big cities than do the large electricity power stations. Anyone in London who is in doubt on this point should ascend the tower at the North End of the Crystal Palace on a fairly clear day, and observe the heavy trail of smoke and fine ash, extending for half-a-mile to a mile, from the four chimneys at the Lots Road electricity station, and similar trails from generating stations at Greenwich and other parts of the Metropolis. The air over the big gas-works, where even more coal is handled, is seen from the same commanding height to be free from any such heavy smoke pall. It is a matter for serious consideration from the standpoint of public hygiene whether generating stations, if still allowed on the outskirts of, or within, our big cities, should not be compelled by law to use only coke or other smokeless fuel, and to adopt adequate means of arresting blown ash-dust.

The directions in which from the chemical standpoint improvements in gas technique have been effected are in the reduction of the proportion of incombustible gases in the gas supplied, and the removal from it, more or less completely, of other obnoxious constituents, such as naphthalene, cyanogen compounds, and carbon disulphide. For the reduction in the proportion of incombustible constituents, the system of charging for gas supplied by the therm instead of by simple volume is largely responsible.

### COKE OVEN GAS.

In certain parts of the country, large quantities of gas—about 2322 million c.ft. in 1926—are being taken by gas undertakings from coke oven works, where the gas had been hitherto a more or less wasted bye-product. The utilization of coke oven gas in this manner is increasing, and would increase at a far more rapid rate were it not for the uncertainty as to the continuity of such supplies of gas at times of labour difficulties at the collieries to which the ovens are attached. The management of coke oven plant does not differ appreciably from that of carbonizing plant at gas-works; and it would appear highly desirable that in every case in which the gas supply of a district is drawn mainly from coke ovens, the ovens should be operated by the gas undertakers instead of by the colliery owners. Such a course would remove the doubts of some of the miners as to whether the coke ovens do not bring undisclosed profits to the colliery proprietors, since the purchase of the coal by the gas undertakers for use in the coke ovens would appear in the ordinary way in the colliery accounts, and the sale of the coke and bye-products would be in the hands of the gas undertakers. The difference between a coke oven works operated by gas undertakers and a gas-works similarly operated would merely be that

in one case the undertakers might have difficulty in disposing economically of surplus gas, whereas in the other case they have at times a superfluity of coke. Gas and coke would change places as the bye-product, but undoubtedly the gas undertakers are in the best position to handle a surplus of either in the general interests of the community. The miners would not have the same objections, in times of labour differences at the mines, to facilitating the supply of coal to coke ovens owned by or leased to gas undertakers as they have had to allowing coke ovens owned by the colliery proprietors to continue at work. In this direction, the responsibility of gas undertakings for the carbonization of coal, whether primarily for gas or for coke production, should be extended.

Concomitantly, in other areas, if the electricity generating stations are required to consume smokeless fuel, they should undoubtedly be put in the hands of the gas undertakers, who would either become responsible for the distribution and retailing of current as well as gas, or would supply the current in bulk to existing electricity distributing organizations. Great economy in the handling of fuel would ensue in many districts if the electricity generating station were an adjunct of the gas-works.

### THE USES OF GAS.

It is not generally realized how largely gas is now consumed for industrial purposes. To go back only to 1912, the peak load of a gas undertaking in winter time would commonly be found at about six o'clock in the evening. On Sunday in the summer months, the peak load in England was between 11 and 1 o'clock, when dinner was being cooked in thousands of small houses. This peak about mid-day on Sunday did not, and does not, occur in Scotland, where hot solid nutriment on that day is taboo. Curves showing the load at different hours of the day at the present time have been furnished to me by a gas undertaking which serves an important industrial and labouring class district in England (fig. 5). The week-day curves refer to Tuesdays, and both week-day and Sunday curves are for days in December (not Christmas week), 1926, and July last. The heaviness of the daylight load on week-days and its uniformity in summer and winter is a principal feature, though the Sunday cooking load still accounts for the highest peak in the curves. It is evident, however, that a regular and very large consumption of gas in factories and works can alone account for the week-day daylight outputs.

Another illustration of the magnitude of the industrial use of gas may be given. There are two contiguous works in Sheffield, belonging to one firm, which consumed in the year 1926 over 88 million c.ft. of gas, having an average calorific value in excess of 500 B.Th.U. per cubic foot. Other works in the same town belonging to the same firm also consumed large quantities of gas, but the figure given refers to the supply to what is practically a single premises. The maximum size of service pipe to any consumer's premises in Sheffield is 14 in. There may be other towns in which industrial works have even larger service pipes and take, individually, larger quantities of gas.

### GAS IN INDUSTRY.

The use of gas for industrial heating dates from before the year 1815, as R. Ackermann, in a letter dated March 13, 1815, stated "my printers employ 16 cockspur burners for ten hours per day to heat their plates instead of charcoal fire." He gives the cost of the charcoal thus dispensed with at £25 per annum. F. Accum, in his book on "Gas-Light," published in 1815, reports that Mr. Cook, a manufacturer of metal toys at Birmingham, saved £30 per annum "in candles, oil, and cotton, for soldering, which since the adoption of gas in his premises has been performed solely by its flame." A firm in Southwark was also reported to be using gas for soldering at that date. At the present time, however, varieties of industrial applications of gas are far too numerous to recite—someone has enumerated 3000. But briefly, it may be said that these include its extensive use by heavy engineering firms, electrical manufacturers, motor-car works, varnish makers and lacquerers, sugar boilers, manufacturing confectioners, bread and biscuit bakers, tool, rivet and chain makers, printers, solder manufacturers, tube makers, and foundrymen.

A development of special interest to chemists in the use of gas for industrial heating purposes lies in the process of submerged combustion, as conducted by Featherstone-Hammond and others. As many of you know, the flame of a mixture of gas and air in proper proportions, and under pressure, is submerged in the liquid which it is desired to evaporate or perhaps merely to keep in molten condition. The economy of such internal heating is obvious; but there are many concomitant advantages in its application to solutions of salts which are liable to dissociate, and to liquids which attack the materials of externally-heated vessels.

### GAS FOR PUBLIC LIGHTING.

There appears to be a tacit assumption in some quarters that gas should give place to electricity for public lighting. It would, however, seem that electricity in reality has no proper sphere in outside lighting, whenever gas and modern gas lighting appliances are available.

In this connection, it is interesting to refer to the recently issued British Standard Specification for Street Lighting. In most respects an admirable document, for which the members of the Sub-Committee who laboured freely and long on its preparation deserve the highest praise, it appears to have one serious defect, in that the high-intensity electric filaments and gasfilled electric lamps may be exposed in clear glass globes in our streets. The method of estimating "glare" given in the specification does not appear to take any account of the distracting effect on drivers of a light source of very high local intensity, and the discomfort it causes to passengers and persons on foot. The attention of the eye is arrested by the brilliant speck of light; the eye is half-blinded, or at least incommoded, thereby, and distracted from the ground and the objects thereon which the light is intended to bring into view. The ideal of good outdoor illumination is that the source of light should attract the attention of the eye as little as possible; and clear-glass electric lamps are the antithesis of this ideal. Their distracting and annoying ill-effects are in certain places—as in the borough of Croydon—multiplied by the fitting of plane mirrors in the street lamps, which have the effect of reflecting the obnoxious filament in nearly horizontal beams in the line of the foot and carriage way. The lamps themselves become the centre of attention, and the objects on the roadway miss the eye. The incandescent gas mantle gives, next, perhaps, to the acetylene flame, the most perfectly self-diffusing source of light; and consequently gas lighting becomes the safest and most satisfactory method of outdoor illumination—especially as it is not subject to the sudden failures over wide areas which occur with electricity.

Comparatively little would have been done in electric street lighting, if it had not been for the fact that seven-elevenths of the electricity supplied in Great Britain is from works belonging to the local authorities, who are also generally the authorities responsible for the public lighting. In several instances the electrical engineer has been appointed the public lighting engineer. One can picture him investigating impartially the relative merits of gas and electricity for street lighting, and the glee with which he would give his verdict in favour of gas. There can be no question that the authority and the engineer responsible for the settlement of questions of public lighting should be in no way connected as owners or servant with either the gas or the electricity undertaking, which are in competition for the lighting of the streets.

The plea that the public lighting load is very useful to the electricity undertaking, and enables it to sell current more cheaply to consumers than it otherwise could, is entirely one-sided. The public lighting load is useful to a gas undertaking also, and enables it to supply gas more cheaply to *its* consumers, whose pockets, generally speaking, are at least as deserving of consideration as the better-lined ones of electricity users.

Given a fair field and no favour, there is no doubt that gas would secure a practical monopoly in street lighting, to the great relief of users of the highway. This observation applies with special force to public lamps, in which the height of the luminous centre of the light source is not more than 18 ft. from the ground, or which are on the outskirts of the zone of public lighting. It also applies very forcibly to detached country towns and villages, as clear-glass or high-power electric lamps in the street there become a very dangerous distraction to drivers approaching from the unlighted country roads.

### GAS SUPPLY IN COUNTRY DISTRICTS.

The innate superiority of gas over electricity for street lighting can only be redressed by the application of screening and diffusing devices to the electric lamps, with consequent waste of their illuminating power. This fact suggests that rural areas should be

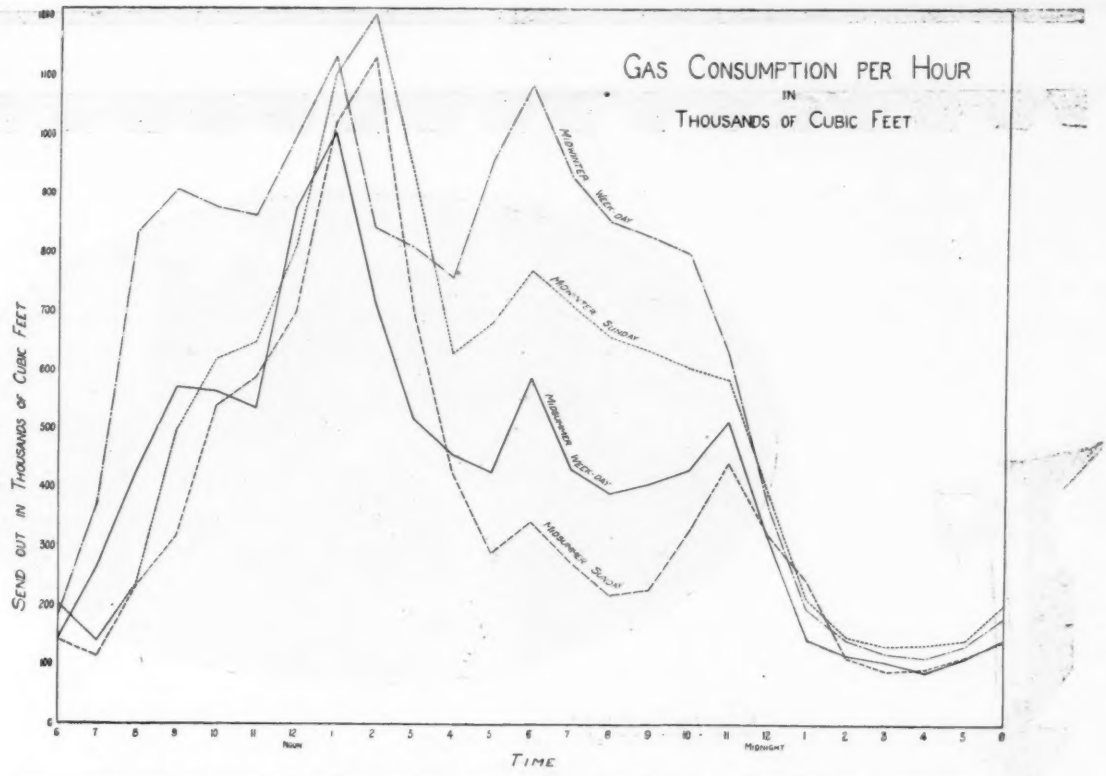



FIG. 5.—CURVES OF HOURLY CONSUMPTIONS, WEEKDAY AND SUNDAY, MIDSUMMER AND MIDWINTER.

given a gas supply before the question of carrying electricity to them by overhead transmission lines is entertained. The poles and lines are eyesores on the countryside, and as air-travel becomes more general will constitute a very grave danger, as the deaths of a balloonist who fouled overhead cables in the northern outskirts of London a few months ago, and of an airman who struck a high-tension cable in France in December, clearly prove. Transmission to rural districts by overhead lines should not be tolerated unless it is shown (1) that there is a substantial demand for it, which gas supply would not meet, and (2) that it cannot be generated as cheaply from coal gas, oil, or other fuel on the spot as it can be supplied through overhead transmission lines from a central generating station.

Electricity can be generated cheaply and conveniently from coal gas, whereas gas cannot be produced from electricity—except in the advertisement pages of "Punch," or inadvertently from the cable insulation, as in recent fatal accidents at Acton and at

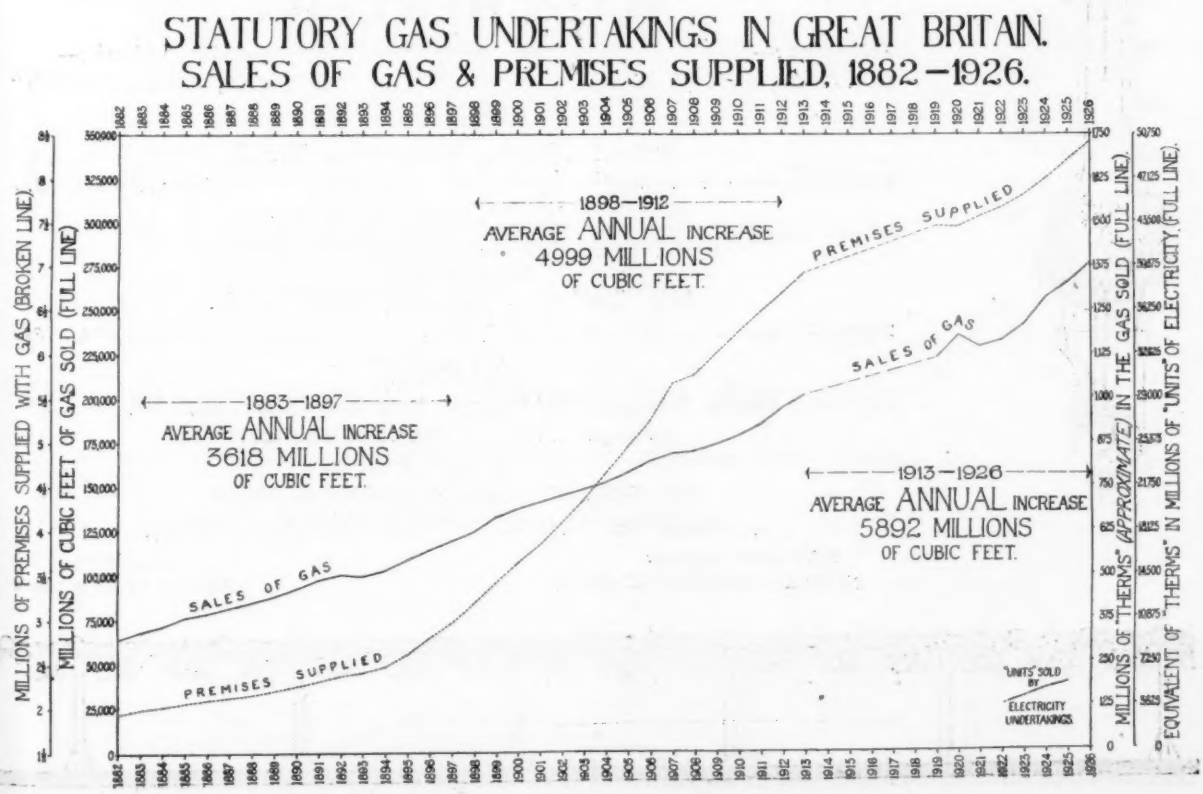
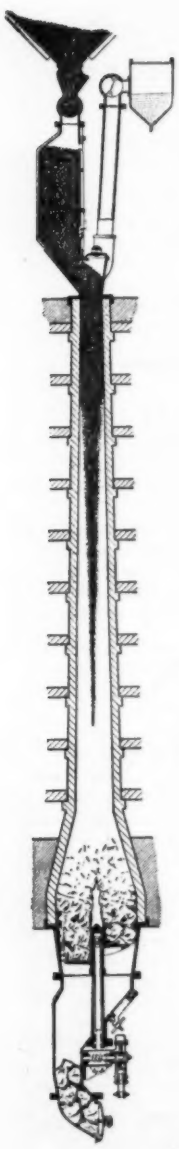
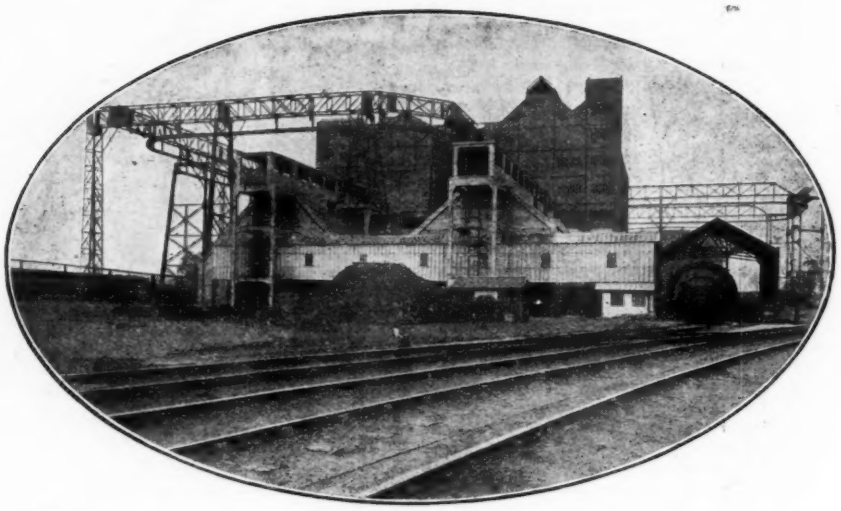

STATUTORY GAS UNDERTAKINGS IN GREAT BRITAIN.
SALES OF GAS & PREMISES SUPPLIED, 1882–1926.
MILLIONS OF PREMISES SUPPLIED WITH GAS (BROKEN LINE).
MILLIONS OF CUBIC FEET OF GAS SOLD (FULL LINE)
MILLIONS OF "THERMS" (APPROXIMATE) IN THE GAS SOLD (FULL LINE).
EQUIVALENT OF "THERMS" IN MILLIONS OF "UNITS" OF ELECTRICITY (FULL LINE).
1898–1912
AVERAGE ANNUAL INCREASE
4999 MILLIONS
OF CUBIC FEET.
1883–1897
AVERAGE ANNUAL INCREASE
3618 MILLIONS
OF CUBIC FEET.
1913–1926
AVERAGE ANNUAL INCREASE
5892 MILLIONS
OF CUBIC FEET.
PREMISES SUPPLIED
SALES OF GAS
"UNITS" SOLD BY ELECTRICITY UNDERTAKINGS.

FIG. 6.—DIAGRAM OF GAS SALES AND PREMISES SUPPLIED, 1882-1926.





*Coventry*

*1st Installation - 1923*
*2nd Installation - 1927*

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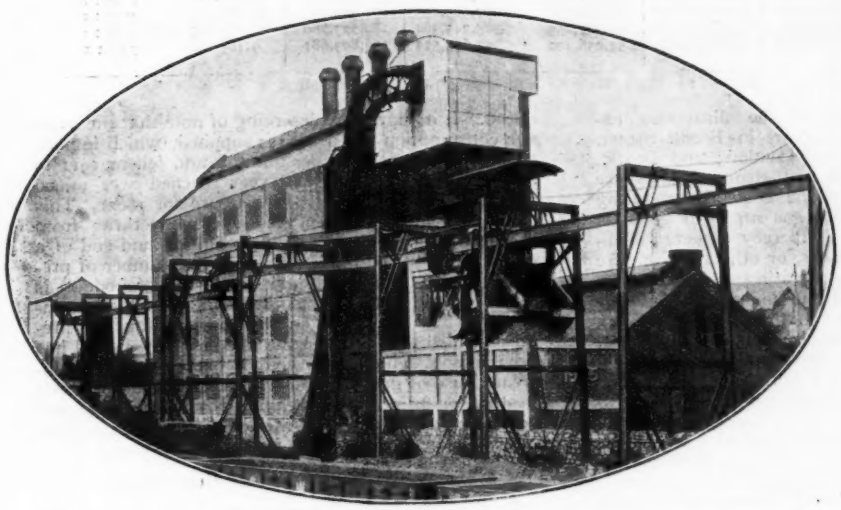


*Torquay*

*1st Installation - 1925*
*Extension now in hand*

*The*
# *Confidence*
## of the Gas Industry in Glover-West Vertical Retorts is shown by the following facts :-

¶ *GLOVER-WEST VERTICAL RETORTS* of a daily capacity of thirty-seven million cubic feet were contracted for during 1927.

¶ *OVER EIGHT THOUSAND RETORTS* are in operation or in course of construction in the principal towns of the five continents.

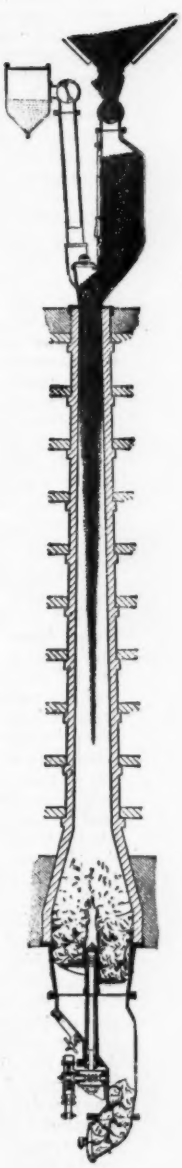


TABLE IV.—"*Therms*" *Sold in Great Britain by Authorized Gas and Electricity Undertakings.*

| Year. | Gas. | | | Electricity. | | | Ratio of Gas Increase to Electricity Increase. |
|---|---|---|---|---|---|---|---|
| | Thousands of C.Ft. | Equivalent in Therms. | Increase on Previous Year. Therms. | Units. | Equivalent in Therms. | Increase on Previous Year. Therms. | |
| 1922 . . . . . | 232,602,789 | 1,163,013,945 | .. | 3,645,190,732 | 125,394,561 | .. | .. |
| 1923 . . . . . | 241,626,603 | 1,208,133,015 | 45,119,070 | 4,338,850,926 | 149,256,471 | 23,861,911 | 1·89 : 1 |
| 1924 . . . . . | 256,891,922 | 1,284,459,610 | 76,326,595 | 4,997,963,253 | 171,929,935 | 22,673,464 | 3·37 : 1 |
| 1925 . . . . . | 265,757,353 | 1,328,786,765 | 44,327,155 | 5,515,345,364 | 189,727,880 | 17,797,945 | 2·49 : 1 |
| 1926 . . . . . | 276,568,647 | 1,382,843,235 | 54,056,470 | 5,723,653,523 | 196,893,681 | 7,165,801 | 7·54 : 1 |

Ardwick (Manchester), and in the disastrous explosions (all since the New Year) in Brook Street, Manchester; Albemarle Street, London; and Bootle. Improvements in small gas and steam engines are imminent, which will lower the cost of generating current from gas. Hence if a gas supply is given to any rural district, electricity is thereby rendered available to country houses, farmers, or others who desire it, either from independent generating sets, or from a local station operated by the gas undertaking. Overhead electrical transmission, on the other hand, will not assist the countryside to obtain a supply of gas, for which, experience proves, there is a greater general demand than for electricity. Figures given later will support this statement. It would appear that Government grants, and guarantees under the Trades Facilities Act, could be more usefully applied towards the extension of gas supply to rural districts than to furthering grandiose schemes of electrical development.

Gas supply to rural districts is already progressing fairly rapidly through private enterprise, and it would advance much faster were it not for the threat of subsidized electricity as a competitor. There are at least three gas undertakings in the South of England alone which send gas under relatively high pressure through small mains to rural districts twenty miles distant from the gas-works, and considerable developments in this direction may be expected in the near future, especially if such schemes are put on equal terms, as regards financial facilities and wayleaves, with electricity supply schemes. Airmen at least will prefer the underground gas main to the overhead transmission line.

### THE GROWTH OF GAS SUPPLY.

A diagram is shown (fig. 6) of the sales of gas and the number of premises supplied with it in Great Britain for the years 1882 to 1926. It has been prepared from the published returns which have been made to the Board of Trade year by year from 1882 to 1926 (omitting the war years 1914-18) by all authorized gas undertakers in Great Britain. The figures for Ireland have been omitted throughout, so that those given in the diagram are strictly comparable over the whole period. It will be seen that development in the use of gas has continued at a progressively increasing rate from 1882 to the present time. This may perhaps best be realized by disregarding the small annual fluctuations, and grouping the whole 45 years covered by the diagram into three approximately equal periods. In the fifteen years 1883-97, the sales of gas increased *each year*, on the average, by 3618 million c.ft. In the next fifteen years, 1898-1912, the average annual increase had risen to as nearly as possible 5000 million c.ft.; while in the last fourteen years, 1913-26, the average increase per annum is no less than 5892 millions. The war years appear to have slowed-down the rate of increase, but the last two or three years have greatly quickened it. The scales on the right-hand side of the diagram show the approximate equivalents in therms of the cubic feet of gas sold, and to how many units of electricity these therms correspond in potential heat development.

As regards the number of premises supplied with gas in Great Britain (shown by the broken line in the diagram), the advance is from 1,031,551 in 1882 to 8,404,561 at the close of 1926. The rate of advance in the number of premises supplied was especially rapid from 1895 to 1907, which period covered the general introduction of the prepayment meter. The average consumption at each premises naturally fell considerably when a new class of consumers was thus introduced. It is, however, deserving of note that the average consumption per premises supplied, which in 1882 was about 33,560 c.ft. per annum, and fell in 1911 to about 28,500 c.ft., had last year reached over 32,900 c.ft., or very little short of the figure for 1882. This close agreement between the average returns from each consumer's meter at the beginning and end of a period of 45 years (in which period the number of premises supplied has multiplied more than four-fold) is a remarkable testimony to the stability of the gas industry. The falling-off in the consumption per premises which took place in the middle of the period has been almost wholly recovered, whether owing to increased use of gas for industrial purposes, or domestic heating, or to increased spending power of a large proportion of the prepayment meter consumers, is a question which does not admit of a simple answer.

### COMPARATIVE FIGURES FOR ELECTRICITY.

In the right-hand lower corner of the diagram are shown the units sold by authorized electricity undertakings in Great Britain in the years 1922-25. These sales do not include current generated by railway companies, tramway authorities, and non-statutory undertakings, which together would add a little over 20 p.ct. to the "sales" figures shown in the diagram. It is obvious, however, that whether the tramway and railway consumption of current is included or omitted, the total number of units of electricity sold in Great Britain is not, on the heat unit basis, yet equal to the sales of gas 45 years ago. Nothing said in this connection refers to electricity generated by users from gas, oil, or steam engines on their own premises. Public supplies of electricity only are being considered.

The most striking aspect of the sales of electricity in recent years is brought out more clearly in Table IV., which shows the equivalents in therms of the gas and electricity sold in 1922-26. The relative annual increases in sales demonstrate that electricity cannot keep pace with gas in the race for public patronage. For every additional unit of electricity which people have bought in the last four years, they have increased their purchases of gas by the heat equivalent of over $3\frac{3}{4}$ times that of the electricity. It is not a case of electricity supply gradually improving its position relatively to gas supply—when the two are put on the comparable basis as distributors of potential heat, electricity is seen to be falling more and more behind gas in the esteem of the community.

### CONCLUSION.

The object of this address has been to portray the development and stability of the one great public utility service which is itself fundamentally a chemical industry, and is the fountain head from which other important chemical industries originate. While the future of gas supply will be advanced by the achievements of the engineer, who is at the moment very busy in remodelling our gasholders, coal and coke handling machinery, and methods of distribution, the chemist is proving himself at least as helpful in his researches, which cover at the moment the principles of carbonization, fuel economy on gas-works, the dehydration of gas before distribution, and a host of problems for the furtherance of efficiency and economy in the use of gas for a thousand different ends. With the support of chemists, who have no reason to be ashamed of their past achievements in connection with it, the gas industry will continue to grow and flourish, and in its turn stimulate the growth and prosperity of other branches of chemical industry.

Paper B. Session I.

# Some Phases of Modern Practice in Gas Manufacture.

By THOMAS HARDIE, M.Inst.C.E, Chief Engineer of the Gas Light and Coke Company.

**Abstract of a paper read before the Institute of Fuel Technology in December, 1926.**

According to the latest Board of Trade returns, the raw materials for gas-making employed by the gas industry in Great Britain during 1925 amounted to—

| | |
|---|---|
| Coal | 17,031,172 tons |
| Oil | 61,382,649 galls. |
| Coke (produced from the coal) | 1,153,413 tons |

These quantities were dealt with by 781 undertakings, of which the largest, the Gas Light and Coke Company, used—

| | |
|---|---|
| Coal | 2,424,924 tons |
| Oil | 21,152,623 galls. |
| Coke | 316,115 tons |

The total coal used by all gas undertakings was stated in the Coal Commission Report of March last* to amount to 9·2 p.ct. of the total coal used in Great Britain.

The heat value of the products sold from a gas-works reaches from 75 to 85 p.ct. of the heat energy in the coal treated. Table I. displays the distribution of heat energy obtained in normal carbonization with modern plant, but without taking into account the increases that can now be obtained by absorbing the heat energy contained in the products, and in waste gases leaving the settings.

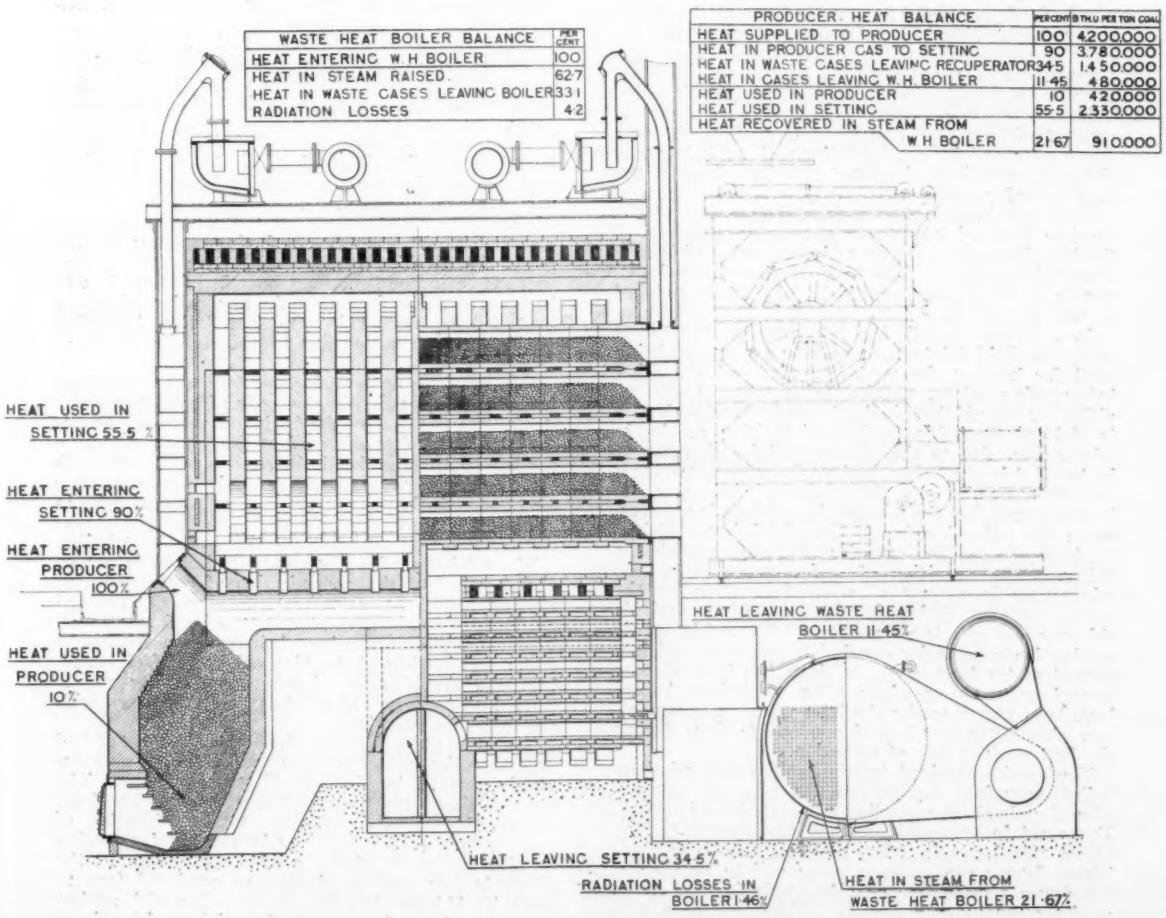
* In this instance, and in several other passages, it must be borne in mind that the paper was originally read in December, 1926.

TABLE I.—*Carbonization of Coal, Horizontal Retorts.*

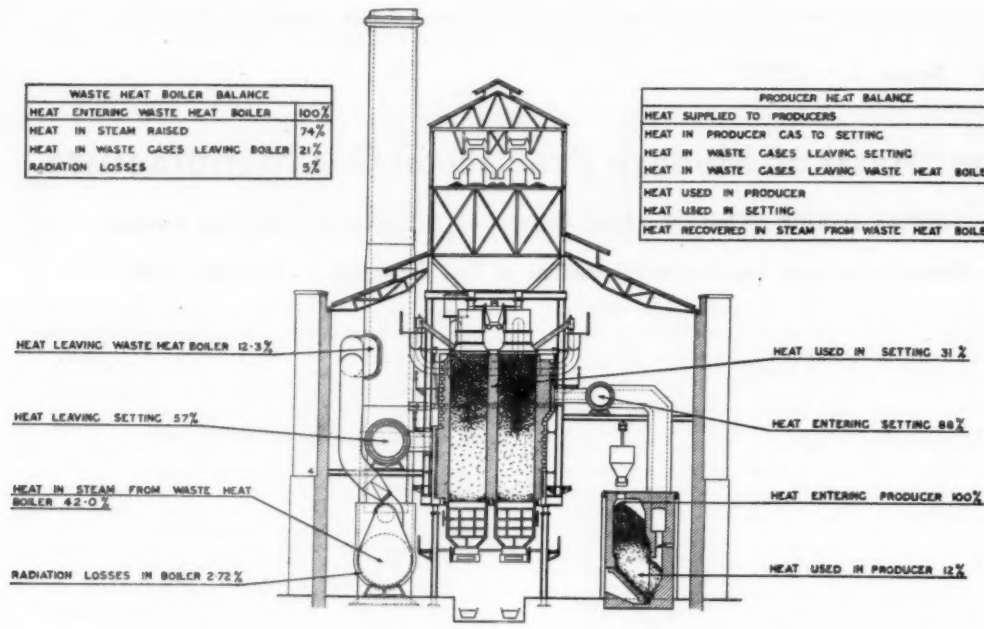
| | B.Th.U. |
|---|---|
| Potential energy in coal— | |
| 1 ton at 13,400 B.Th.U. per lb. = | 30,016,000 |
| Products of carbonization— | |
| Gas, 13,160 c.ft. of 545 B.Th.U. | 7,172,000 |
| Tar, 9·35 galls., at 185,000 B.Th.U. per gallon | 1,729,750 |
| Coke and breeze, 14·5 cwt., at 12,284 B.Th.U. per lb. | 19,950,000 |
| Heat in combustible products, neglecting ammonia, retort carbon, &c. | 28,851,750 |
| Thermal efficiency of conversion = 96 p.ct. | |
| Products used on works in process— | |
| Coke for heating retorts, 3 cwt., at 12,500 B.Th.U. per lb. = | 4,200,000 |
| Breeze for obtaining power, 1 cwt., at 10,000 B.Th.U. per lb. = | 1,120,000 |
| Total heat used on works | 5,320,000 |
| Products for sale to public— | |
| Gas, 13,160 c.ft. at 545 B.Th.U. | 7,172,000 |
| Tar, 9·35 galls. | 1,729,750 |
| Coke, 10·25 cwt., at 12,500 B.Th.U. per lb. | 14,350,000 |
| Breeze, 0·25 cwt., at 10,000 B.Th.U. per lb. | 280,000 |
| | 23,531,750 |

Commercial efficiency of process, 78·4 p.ct.

NOTE.—If all power is derived from waste-heat steam, then 1¼ cwt. of breeze are for sale, and the efficiency becomes 82·5 p.ct.


WASTE HEAT BOILER BALANCE | PER CENT
HEAT ENTERING W.H BOILER | 100
HEAT IN STEAM RAISED. | 62·7
HEAT IN WASTE GASES LEAVING BOILER | 33·1
RADIATION LOSSES | 4·2
PRODUCER HEAT BALANCE | PERCENT | B.TH.U PER TON COAL
HEAT SUPPLIED TO PRODUCER | 100 | 4,200,000
HEAT IN PRODUCER GAS TO SETTING | 90 | 3,780,000
HEAT IN WASTE GASES LEAVING RECUPERATOR | 34·5 | 1,450,000
HEAT IN GASES LEAVING W.H. BOILER | 11·45 | 480,000
HEAT USED IN PRODUCER | 10 | 420,000
HEAT USED IN SETTING | 55·5 | 2,330,000
HEAT RECOVERED IN STEAM FROM W.H BOILER | 21·67 | 910,000
HEAT USED IN SETTING 55·5 %
HEAT ENTERING SETTING 90%
HEAT ENTERING PRODUCER 100%
HEAT USED IN PRODUCER 10%
HEAT LEAVING WASTE HEAT BOILER 11·45%
HEAT LEAVING SETTING 34·5%
RADIATION LOSSES IN BOILER 1·46%
HEAT IN STEAM FROM WASTE HEAT BOILER 21·67%

CROSS-SECTION OF A HORIZONTAL INSTALLATION AT BECKTON.


WASTE HEAT BOILER BALANCE
HEAT ENTERING WASTE HEAT BOILER 100%
HEAT IN STEAM RAISED 74%
HEAT IN WASTE GASES LEAVING BOILER 21%
RADIATION LOSSES 5%
PRODUCER HEAT BALANCE
B.Th.U. PER TON COAL
HEAT SUPPLIED TO PRODUCERS 100% 3,668,000
HEAT IN PRODUCER GAS TO SETTING 88% 3,227,840
HEAT IN WASTE GASES LEAVING SETTING 57% 2,090,000
HEAT IN WASTE GASES LEAVING WASTE HEAT BOILER 12·3% 450,000
HEAT USED IN PRODUCER 12% 440,160
HEAT USED IN SETTING 31% 1,137,840
HEAT RECOVERED IN STEAM FROM WASTE HEAT BOILER 42·0% 1540,000
HEAT LEAVING WASTE HEAT BOILER 12·3%
HEAT LEAVING SETTING 57%
HEAT IN STEAM FROM WASTE HEAT BOILER 42·0%
RADIATION LOSSES IN BOILER 2·72%
HEAT USED IN SETTING 31%
HEAT ENTERING SETTING 88%
HEAT ENTERING PRODUCER 100%
HEAT USED IN PRODUCER 12%

HEAT BALANCE CHART OF W-D VERTICAL RETORTS AT THE GAS LIGHT & COKE COMPANY'S BOW COMMON WORKS.

CROSS-SECTION OF BOW COMMON INSTALLATION OF 3 VERTICALS.

## WASTE-HEAT RECOVERY.

The waste gases leave the retort settings at a temperature up to 1000° C., and contain energy equal to 50 to 60 p.ct. of that produced by the combustion of the producer coke. Until the past few years, this energy was recovered only to the extent that it could be utilized to heat the secondary air required for combustion; the air being raised to between 550° and 650° C. in the usual form of recuperator, and about one-half of the available sensible heat of the waste gases being absorbed. At the outlet of the recuperator the gases entered the chimney duct at a temperature of about 700° C., and served no other purpose than that of creating the requisite draught. Where external producers were employed, a certain amount of heat was abstracted to preheat the producer gas; and in certain designs of vertical retorts the hot gases were circulated round portions of the retorts, and no recuperators employed.

With the intention of making better use of the sensible heat of the waste gases, the recovery of the heat in steam boilers was introduced, and is now extremely popular. The final temperature of discharge of the waste gases is by this means reduced to 200° to 250° C.

In a recent installation in Germany, the waste gases are divided into two streams; one stream being used for heating the secondary air, and the other being taken direct to the boiler. In theory no difference should be obtained in the results, but it is claimed that this method of division results in advantages, due to the smaller weight of gases to be handled in the boiler, and to the greater temperature difference between the gases and the water. It is also stated that the intervention of fans is unnecessary; the natural chimney draught being sufficient to draw the smaller quantity of gases through the boiler. The provision of a fan possesses certain advantages in respect of a steady suction on the retort settings, which in the case of a variable chimney draught is non-existent. That this steady suction leads to easier regulation and more efficient control of the heat of the settings has been demonstrated on most occasions when waste-heat boilers have been put to work; the inlet waste gas temperature showing a steady and appreciable drop during the first week or two of operation.

The results obtained by the employment of these boilers vary from 600 to 1500 lbs. of steam per ton of coal carbonized, according to the design of setting. Expressed in terms of producer fuel consumed, the steam raised equals 1·8 to 4·5 lbs. per lb. of fuel. These figures are gross outputs; and to obtain the net figure a reduction must be made for the steam used for the induced draught. Expressed as a proportion of the energy in the producer fuel, the heat in the gross steam recovered varies with the type of setting from 15 to 45 p.ct.

## CARBURETTED WATER GAS.

In 1925 the volume of carburetted water gas produced amounted to 17 p.ct. of the total gas produced in the country. The advantages of its manufacture lie in its value as reserve plant, quickly put in or out of action, in using surplus coke, and, as in the present industrial situation, as a means of coal conservation.

The principal loss of heat—*i.e.*, in the spent blast gases—is recoverable in waste-heat boilers; and the attachment of these boilers to water gas plant has become standard practice during the past seven years.

The amount of steam normally raised in the waste-heat boiler varies from 1¼ to 2¼ lbs. per pound of coke consumed in the generator, or from 50 to 90 lbs. per 1000 c.ft. of gas made.

The steam requirements of carburetted water gas plants for all purposes, including process steam, power for air blowers, gas exhausters, pumps, &c., average 80 to 100 lbs. per 1000 c.ft. of gas. It will be apparent, therefore, that the application of waste-heat boilers results in the installation becoming practically self supporting in the matter of steam supply.

Of more recent introduction than the waste-heat boiler is an alteration in the mode of operating water gas plants, known as the back-run process. Essentially this consists of passing the steam during a portion of the run in the reverse direction through the superheater, carburettor, and thence to the generator. This reduces the consumption of coke in the producer per 1000 c.ft. of gas made, but also reduces the heat available for the waste-heat boiler.

The efficiency of water gas manufacture is not so high as that of the carbonization of coal. Without oil enrichment or waste-heat recovery, the thermal efficiency of water gas manufacture is 46 to 50 p.ct. The addition of waste-heat boilers raises this to 60 p.ct.; and in view of the high efficiency of oil cracking, the manufacture of carburetted water gas is carried on nowadays at nearly 70 p.ct. efficiency with the most modern plant.

The attempts to increase the economical use of fuel on gas-works in recent years are by no means completely covered by the preceding particulars. The greatest departure from ordinary practice has been the erection of plants for the total gasification of coal. Plants of this type are in successful operation in different parts of the country; but, due to the relatively low quality of the gas produced (250 to 400 B.Th.U.), to difficulties in operation with all but selected coals, and to certain financial considerations,

these plants are not attractive to the larger undertakings.

Low-temperature carbonization has so far proved even less attractive to gas undertakings than total gasification.

APPLICATION OF WASTE-HEAT RECOVERY BY THE GAS LIGHT AND COKE COMPANY.

*Carburetted Water Gas.*—The first installation of a waste-heat boiler in connection with this type of plant was undertaken in 1919, at which date no similar installation existed in any other gas-works in the country. Since then 46 boilers have been put in hand, of which 40 are at work. The present total hourly evaporation of these boilers is 128,500 lbs. of water, which is equal to an average of 38·6 lbs. per 1000 c.ft. of the maximum output of all plants. Under these conditions, 70 p.ct. of the steam required for process and power plants is supplied to the plants equipped, which are normally those most worked; and 48 p.ct. of the steam needed with all plants in operation is provided by waste heat.

*Coal Gas.*—The installation of boilers attached to retort settings was commenced in 1923, so that the proportion of plants equipped is not high. Nevertheless, 26 boilers are at work at present, and 11 more are in course of erection, and would have been at work but for the present industrial situation. The boilers actually in use are evaporating a total of 145,116 lbs. of water per hour—a figure which will shortly be increased to 220,000 lbs. as the remaining boilers are put to work. The steam raised per ton of coal carbonized in the equipped plants averages 1050 lbs. per ton, and, calculated on the maximum daily use of coal by the Company, 10,000 tons, is sufficient to give at the moment 348 lbs. of steam per ton of coal, and 528 lbs. in the immediate future. The first of these figures is equal to one-half, the second to 75 p.ct., of the present steam requirements of the gas-works.

With the total of 83 waste-heat boilers at work, the steam produced by them will amount to 4000 tons per day, which releases for sale to the public 600 to 700 tons of fuel daily.

Tables II. and III. are typical statements showing the thermal efficiencies that are obtained in everyday working in the newer carbonizing and carburetted water gas plants of the Gas Light and Coke Company. The efficiency in the carbonizing plant is shown to be 85·6 p.ct.—an advance slightly exceeding 7 p.ct. over the older types of plant, due to the recovery of heat from the products of carbonization, and from the waste heating gases. The corresponding efficiency of horizontal retorts with waste-heat recovery has reached 82·5 p.ct.—an advance of 4 p.ct. The efficiency of the carburetted water gas plant is by the nature of the process inferior to that of the carbonization plant, but nevertheless reaches 69·2 p.ct.—an advance of 9·3 p.ct. in consequence of heat recovery from the spent blast gases. Rather better figures are expected from units operating on the new back-run processes; but no exact tests have as yet been possible.

TABLE II.—*Carbonization of Coal in Continuous Vertical Retorts Equipped with Waste-Heat Recovery.*

| | B.Th.U. |
|---|---|
| Potential energy in coal— | |
| 1 ton at 13,400 B.Th.U. per lb. . . . . = | 30,016,000 |
| Products of carbonization— | |
| Gas, 15,300 c.ft. at 510 B.Th.U.. . . . | 7,803,000 |
| Tar, 11 galls., at 181,810 B.Th.U. per gallon | 2,000,000 |
| Coke and breeze, 13·83 cwt., at 12,242 B.Th.U. per lb. . . . . | 18,964,400 |
| Heat in combustible products . . . | 28,767,400 |
| Thermal efficiency of conversion = 95·84 p.ct. | |
| Products used on works in process— | |
| Coke for heating retorts, 2·62 cwt., at 12,500 B.Th.U. per lb. . . . . | 3,668,000 |
| All power from waste-heat steam, and similarly steam to retorts. | |
| | B.Th.U. |
| Products for disposal to public— | |
| Gas, 15,300 c.ft., at 510 B.Th.U. . . . | 7,803,000 |
| Tar, 11 galls. . . . . | 2,000,000 |
| Coke, 9·79 cwt., at 12,500 B.Th.U. per lb.. | 13,706,000 |
| Breeze, 1·42 cwt., at 10,000 B.Th.U. per lb. | 1,590,400 |
| Steam, surplus for other purposes not required for power or gas production . . | 596,000 |
| | 25,695,400 |
| Commercial efficiency of process, 85·6 p.ct. | |

TABLE III.—*Gasification of Coke and Oil for the Production of Carburetted Water Gas with Recovery of Waste Heat.*

| | B.Th.U. |
|---|---|
| Heat in coke to generators (gross amount), 32 lbs., at 12,500 B.Th.U. per lb. . . . . | 400,000 |
| Heat in oil, 2 galls., at 165,000 B.Th.U. per gall. | 330,000 |
| Heat in 4 lbs. of breeze for steam raising, at 10,000 B.Th.U. per lb. . . . . | 40,000 |
| | 770,000 |

The 4 lbs. of breeze produces 20 lbs. of steam. A further 60 lbs. is produced by the waste-heat boilers. The total of 80 lbs. completely supplies all power and process steam required. If there are no waste-heat boilers, 16 lbs. of breeze (160,000 B.Th.U.) are required for steam raising.

| | B.Th.U. |
|---|---|
| Heat in carburetted water gas made 1000 c.ft., at 495 B.Th.U. per c.ft. . . . . | 495,000 |
| Heat in tar produced 0·2 gall., at 190,000 B.Th.U. per gall. . . . . | 38,000 |
| | 533,000 |
| Commercial efficiency of process, 69·2 p.ct. | |

NOTES.—(1) Without waste-heat recovery, the efficiency would be 59·9 p.ct.

(2) If water gases and blast gases pass through boiler, as with blue water gas plants, steam generated is 85 lbs. per 1000 c.ft. of gas.

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**Paper C. Session I.**

# Presidential Address to the Southern Association of Gas Engineers and Managers, 1927.

**By THOMAS HARDIE, M.Inst.C.E., Chief Engineer of the Gas Light and Coke Company.**

**Abstract.**

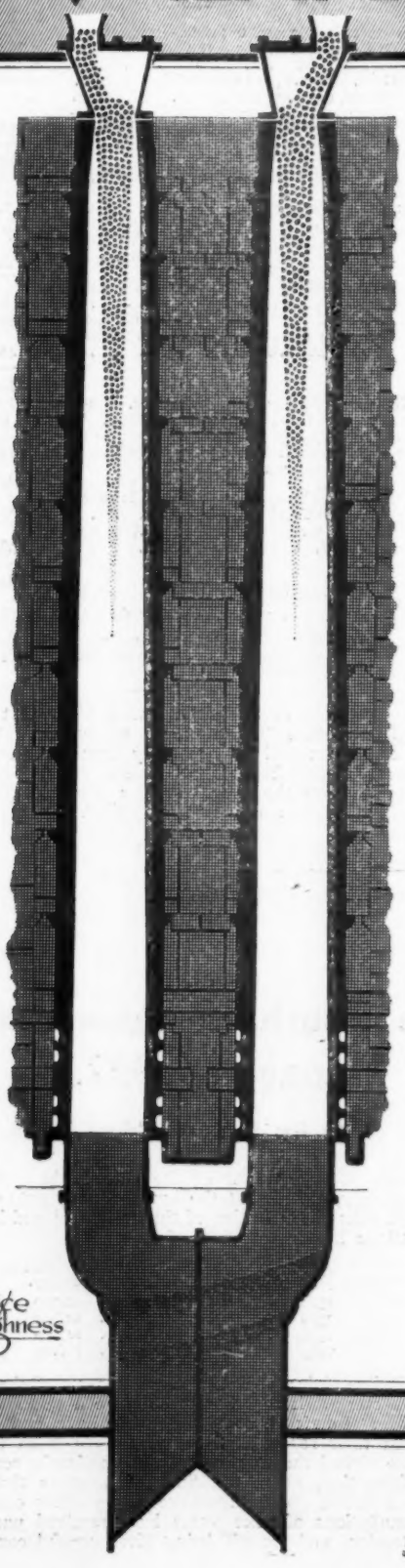
The annual increase of 1774 million c.ft. of the Gas Light and Coke Company for the last few years necessitates an increase in manufacturing capacity each year of approximately 8 million c.ft. per day. For some years it was possible to meet these increases from surplus plant and by increasing the output of existing plant. Most of the surplus plant in existence has now been reconstructed and put again into operation, and most of the existing plant has been tuned up to its maximum output. Larger furnaces, higher and more regular temperatures in the retort settings, and more efficient control have all provided their quota towards the larger output from individual units of retort house plants. At the same time alterations to water gas plants have resulted in increased outputs up to 100 p.ct.

Considering, for example, the returns relating to seven of the stations of the Gas Light and Coke Company, I find that the average daily output from each retort in operation of the horizontal and inclined settings has increased as follows:

| Year. | C.Ft. per Retort per Day. |
|---|---|
| 1900 . . . . . | 11,300 |
| 1910 . . . . . | 12,800 |
| 1920 . . . . . | 14,600 |
| 1925 . . . . . | 16,100 |

Before giving you particulars of some of the reconstruction work that has recently been undertaken, I might remark that my Company have had reports from their representatives, who have from time to time visited the Continent and America in search of information, as to the lines of progress that have been found most advantageous in other countries. Installations of coke ovens have received particular attention, and are still being given careful considera-

# DRAKES VERTICALS



*embody the results of 80 years' experience in the science of Carbonization.*

1 The method of draughting is scientifically correct—there is, consequently, an absolute freedom from tar troubles while maintaining the highest permissible heats that the very best refractories will stand.

2 The heats are stable and non-cutting. The retorts are soaked in a steady controlled temperature uniformly maintained.

3 Immunity from hanging charges and consequent "rodding."

4 The control is simplicity itself both for heats and throughput.

5 Startlingly cool and spacious working platforms.

6 Highly efficient coke extraction.

7 Ample provision for inspection. Interior of retorts accessible without disturbing extractor.

8 ABSOLUTE RELIABILITY in every respect.

**All these unite to form one convincing combination which impresses the beholder with a conviction of CHARACTER, STAMINA & VITALITY**

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tion, as under certain conditions, particularly for large installations, they may have advantages over other types of carbonizing plant. It has not yet been possible, however, to show a balance sufficiently favourable to justify the installation of this type of retorting plant in the Gas Light and Coke Company's area when all the conditions, in regard to both erection and working, are taken into account for specific instances. Other conditions, however, may easily throw the balance in favour of coke ovens; and when these arise I shall have no hesitation in recommending this method of carbonizing to the consideration of my Directors.

### RECONSTRUCTION PROBLEMS.

The amalgamation with the Brentford Company brought the number of our manufacturing stations in regular work up to thirteen; and the choice of the station at which new plant shall be installed is sometimes difficult. With manufacturing stations varying in size between 1½ millions and 100 millions in daily output, differing greatly in their facilities for receiving coal, and in the demand of the districts surrounding them for coke, the difference in the net coal cost of manufacture between station and station is considerable. The type of carbonizing plant alone has not the most important influence on manufacturing costs. Reconstruction is only undertaken when the existing plant has reached the end of its economical and efficient life, and considerable expenditure on repairs has become essential. In Table I. will be found a comparison of the results obtained in three representative types of retort house plant.

It will be seen that there is little difference in the labour costs of a modern horizontal retort house and of a present-day vertical retort plant; and the reason which has led us to adopt vertical retorts in several of our recent reconstructions has been mainly the necessity of obtaining the largest possible output of gas upon a given ground area. We have not found that any one vertical retorting system possesses sufficient outstanding features to justify our exclusive choice; and as each reconstruction involving the use of vertical retorts becomes due, the selected plant results from the best tender submitted. To date the vertical retort plant of the Gas Light and Coke Company consists of 14 million c.ft. per day each of the Glover-West and the Woodall-Duckham designs. In the comparison given in the table, though the horizontal retort house is 100 ft. wide, yet the same output could have been obtained had it only a width of 65 ft., and the comparative therms per square foot per day would then have been 1·48 as against 2·71 with vertical retorts. In a house specially constructed for vertical retorts, the figure 2·71 would be improved.

### ALTERATIONS AT THE BOW COMMON WORKS.

As an example of reconstruction work, I propose to give you some particulars of the alterations which are now being made at Bow Common. This case is a simple one, as the completed works will have but a single retort house, whereas at other stations the reconstruction has resulted in a portion only of the carbonizing plant being renewed.

With the old inclined retorts the daily output of coal gas was 5·5 million c.ft., which, together with the carburetted water gas plant, produced a total output of 8 million c.ft. per day. As now reconstructed the output is made up of coal gas from vertical retorts, 8 million c.ft., and carburetted water gas 2·5 million c.ft.—a total output of 10·5 million c.ft. per day (500 B.Th.U.).

The reconstructed plant, together with gasholder storage of nearly 4,500,000 c.ft., coal storage equal to 30 days' maximum consumption, 14 days' coke storage, Engineer's residence, and all the usual appurtenances of a gas-works, occupies 9·5 acres, so that the area per million c.ft. is 0·905 acre. This is the fourth of the Company's stations wherein the acreage per million is less than one. It will be recognized how necessary it is in London, where suitable sites for gas-works are to-day practically unobtainable, that the greatest possible use should be made of every favourably situated existing site.

The carbonizing plant consists of an installation of Woodall-Duckham vertical retorts in two benches each of 34 retorts. The retorts are 25½ ft. long, rectangular in section, 78 in. by 10 in. at the top and 81 in. by 18 in. at the base. Each retort is capable of dealing with 7·53 tons of Yorkshire coal in 24 hours, and the carbonizing capacity of the plant is 512 tons daily, from which is guaranteed a yield of 8,038,000 c.ft., or 40,960 therms of 510 B.Th.U. gas. The make of gas per ton is thus 15,700 c.ft., and the therms are approximately 80 per ton of coal carbonized.

The heating of the retorts is carried out by two batteries each containing five producers erected independently of the retort bench at one side of the retort house and feeding the settings by a common producer gas main running the length of the benches.

No regenerators are installed, but there are three waste-heat boilers. Two of these are normally in action, leaving the third as a stand-by, so that a full output of steam is always assured during periods of cleaning or repairs to one of the boilers. The guaranteed consumption of fuel is 2·8 cwt. of cold coke per ton of coal carbonized, while the water evaporation from the boilers should be not less than 5·45 lbs. (from and at 212° Fahr.) per lb. of producer fuel.

After allowing for the steam used by the turbines driving the induced draught fans, the net output of steam at 130 lbs. per sq. in. and 500° Fahr. should be 31,800 lbs. per hour, which is equal to 1490 lbs. per ton of coal carbonized.

The area occupied by the new carbonizing plant is now 13,420 sq. ft., giving an output of 600 c.ft., or 3·06 therms per sq. ft. of ground space, which compares with 212·8 c.ft. and 1·15 therms of the

TABLE I.

| Type of Plant. | Inclined. | Horizontal. | Continuous Verticals |
|---|---|---|---|
| Size of retort house | 310 ft. by 63 ft. | 360 ft. by 100 ft. (65 ft.) | 192 ft. by 60 ft. |
| Number of retorts | 240 | 270 | 128 |
| Size of retorts | 24 in. by 14 in. by 20 ft. | 24 in. by 18 in. by 23 ft. | 33 in. by 10 in. to 39 in. by 25 in. |
| Power | Steam | Electric | Electric |
| Coal | Midland | Durham | Durham |
| Coal per month (average) | 9200 | 14,400 | 12,400 |
| Coal per full day | 306 | 480 | 400 |
| Charge per retort | 9·2 cwt. | 19·5 cwt. | 3·4 tons per day |
| Duration | 8 5 hours | 12·0 hours | .. |
| Coal per retort (working) per day | 1·3 tons | 1·95 tons | 3·4 tons |
| Therms per retort (working) per day | 94·9 | 140·4 | 265·2 |
| Therms per ton | 73 | 72 | 78 |
| Therms per day | 22,338 | 34,560 | 31,200 |
| C.ft. per day | 4,150,000 | 6,250,000 | 6,120,000 |
| Average of retorts gas-making | 235 | 246 | 117 |
| Area of site, sq. ft. | 19,500 | 36,000 (23,400) | 11,520 |
| C.ft. of gas made per 24 hours per sq. ft. of site | 212·8 | 173·5 (267·1) | 531·2 |
| Therms ,, ,, ,, ,, ,, | 1·15 | 0·96 (1·48) | 2·71 |

CARBONIZING WAGES, PENCE PER TON OF COAL CARBONIZED.

| | | | |
|---|---|---|---|
| Coal (from delivery to crushers to bunkers) | 1·75 | 0·54 | 0·42 |
| Carbonizing (coal from bunkers to coke to conveyors and furnaces) | 23·79 | 11·12 | 11·18 |
| Coke (coke from retort house to storage in bunkers) | 16·00 | 0·93 | 1·04 |
| Incidentals (foremen, lobbies, &c.) | 3·54 | 3·31 | 3·29 |
| Total wages | 45·08 | 15·90 | 15·93 |

NOTE.—The above retort house now fitted with continuous verticals was originally an inclined retort house making 2 million c.ft. of gas per day.

inclined retorts previously installed in this retort house.

### COSTS.

As may be expected, the carrying-out of several of these reconstruction schemes has placed the Company in the possession of data as to present-day gas-works construction costs; and I give in Table II. some averages of costs which, while being definitely applicable to extensions of 5 to 7 million c.ft. per day, will, I hope, be of more general value.

### MORE EFFICIENT WORKING.

There has been reached in recent years a greatly improved standard of operation in gas-works. More efficient working is general, and greater attention is now given to detail than at any previous time. The employment of chemists in large numbers has assisted in concentrating attention upon sources of loss which are now avoided; and the scientific control of working results in increased efficiency.

The more careful examination of coals has led to a greater accuracy in discrimination. While colliery owners no doubt recognize fully the need for efficient means of cleaning coal, they still continue to deliver many varieties with excessive quantities of ash; and it may be that the increasing demand for coke for domestic purposes will make it essential for gas undertakings themselves to instal one or other of the cleaning processes which are each year becoming more and more effective and more easily applicable.

TABLE II.—*Costs of Reconstruction of Existing Works, Including Foundations, Contract and Direct Labour, and Connections.*

COAL GAS PLANT.

| — | Per Million C.Ft. per Day. | Per Ton of Coal per Day. |
|---|---|---|
| | £ | £ |
| Carbonizing plant and waste-heat boilers | 16,100 | 249·6 |
| Condensers | 1,290 | 20 0 |
| Exhausters | 650 | 10·1 |
| Livesey washers | 190 | 2·9 |
| Ammonia washers | 1,050 | 16·3 |
| Naphthalene washers | 520 | 8·1 |
| Purifiers with oxide handling plant | 5,100 | 79·0 |
| Station meters | 900 | 13·9 |
| Electric power plant | 1,300 | 20·2 |
| Coal unloading plant | 1,700 | 26·4 |
| Coal handling and storage plant | 1,420 | 22·0 |
| Coke handling plant | 1,620 | 25·1 |
| Mains, services, and cables | 2,600 | 40·3 |
| Tar and liquor storage | 1,300 | 20·2 |
| Ash handling plant | 840 | 13·0 |
| Gasholders (12 hours' make) | 9,300 | 144·2 |
| | £45,880 | £711·3 |

**Paper D. Session 1.**

# Continuous Vertical Retorts.

**By M. BARASH, M.Sc.(Tech.), A.I.C., and T. CAMPBELL FINLAYSON, M.Sc., A.M.I.Chem.E.**

### INTRODUCTION.

The success attained by the various systems of carbonization in continuous vertical retorts is one of the outstanding features in gas engineering during the past two decades. Twenty years ago, continuous carbonization was in an experimental stage. To-day, it is computed that over 50 p.ct. of the coal carbonized in British gas-works is dealt with in continuous vertical retorts. For there to have been such a general acceptance of new methods of carbonization in a comparatively short period, continuous vertical retorts must hold some very big attractions for gas engineers.

The authors believe that they will be falling in with the spirit of the Carbonization Conference by presenting a paper which examines closely the various characteristics common to the different designs of continuous vertical retorts, rather than by initiating discussion on the relative merits of different makes of plant which have the same general principles in view.

### THE PROCESS IN BRIEF.

In brief, the process of carbonization in a continuous vertical retort is as follows: Coal is elevated to an overhead storage bunker. From this overhead bunker the coal is allowed to fall at intervals into an auxiliary hopper fixed over the vertical retort. From the auxiliary hopper, the coal enters the top of the retort through a mouthpiece casting, the rate of introduction of coal being governed by the speed of extraction of coke from the bottom of the retort. The retort, which is suitably tapered, is constructed of high-quality refractory materials. The speed of descent of the coal is so regulated that the coal entering at the top is gradually carbonized and converted into coke by the time it arrives at the bottom. The coal as it passes through the retort is heated, and the various gases and bye-products are evolved as the coal reaches the necessary temperatures. The coke is cooled in the lower parts of the retort either by steam or water, and is discharged from a hopper underneath the extractor at regular intervals in a dry, cool condition. By the introduction of steam at the bottom of the retort, not only is the coke cooled, but the major portion of the heat in the coke is utilized for the production of water gas within the retort. The gas passing up to the top of the retort is cooled by contact with cold coal, and thus also leaves the retort in a cool condition.

The retort is heated by the combustion of producer gas in a series of combustion chambers adjacent to the retort.

### CONTINUOUS CARBONIZATION.

From the earliest days of carbonization, attempts have been made to replace the intermittent method of charging retorts with coal and removing the coke after a definite period by some device in which the coal would pass into the retort continuously at one end while the residual coke would be withdrawn at the other end.

It was seen by the early inventors that the following advantages would accrue from such a continuous method of carbonization:

(*a*) Every section of the charge would pass through exactly the same process as every other section. The unavoidable defect in all intermittent processes is that the ends of the charge, whether vertically or horizontally placed in the retort, or on the incline, are not subjected to the same heat treatment as the middle of the charge.

(*b*) The refractory material of which the retort and its setting are constructed can, in a continuous system, be maintained under constant temperature conditions, thereby avoiding damage due to more or less sudden alternate heating and cooling.

(*c*) The continuous system entirely avoids the very great and very inconvenient variations in the quality and quantity of gas given off during the periods of intermittent working. This difficulty is commented upon by many scientific writers and investigators of carbonizing methods, and in the "JOURNAL OF GAS LIGHTING," Vol. 117, p. 888, Dr. W. B. Davidson gave an account of his experiences in the experimental gas-works at Birmingham bearing upon this point.

Fig. 1 shows the variation in the rate of

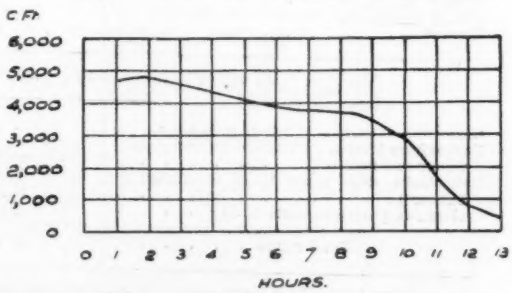



Fig. 1.

evolution of gas from coal carbonized in an intermittent vertical retort over a period of thirteen hours.

Fig. 2 shows the variation in the composition and calorific value of the gas generated in the same retort.

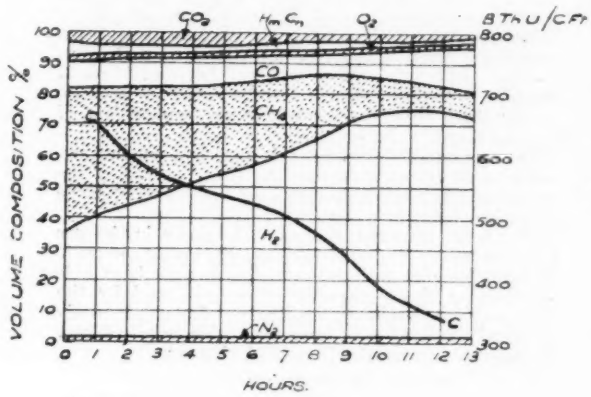



Fig. 2.

The corresponding diagrams for a continuously operated retort would be almost horizontal lines extending for an indefinite period.

(*d*) The fact that gas from a continuously operated retort is given off constant in quality and quantity has important bearings upon the auxiliary plant of the gas-works and upon the conditions of supply to the district.

It was shown by the late Mr. J. G. Newbigging (see "JOURNAL OF GAS LIGHTING," 1911, Vol. 114, p. 864), that the capacity of the purification plant was increased considerably when the gas was passed through at a constant rate and of a constant composition.

Variations in quality in intermittent systems are dealt with as far as possible by "stepping" the times of charging and discharging the separate units, and by providing suitable gasholder accommodation. These measures, however, still leave it necessary to produce gas of an average calorific value at the retorts higher than the declared value in the district, in order to avoid penalties under the Gas Regulation Act, with a consequent loss of several therms per ton which cannot be charged for in gas accounts.

This margin of safety can be reduced to very narrow limits when a continuous process of carbonization is employed.

(*e*) A continuous process can be accelerated or retarded as required without affecting the actual operations performed by the stokers in the retort house. It was found to be a serious difficulty in intermittent systems that charging and discharging operations must necessarily be fixed to be performed at certain definite hours which cannot be varied at short notice.

The vertical retort is the only form in which continuous carbonization has so far been realized on a large and commercially successful scale. In this type of plant there is complete realization of the advantage of passing the coal through the retort by means of gravity. The mechanism of charging and discharging is, therefore, reduced to its simplest form. Charging and discharging machinery in the form of heavy moving machines, expensive both in first cost and maintenance, is entirely eliminated. The retort being always closed, losses of gas in the charging operation are eliminated.

### DETAILS OF DESIGN.

In the design and construction of retorts on this principle, the following factors are of great importance:

#### (A) EVEN AND REGULAR FEED OF COAL AND EXTRACTION OF COKE.

The extraction of coke governs the rate of feed of coal; and the efficiency of the extractor is of the utmost importance. The two fundamentals of an efficient coke extractor are:

(*a*) It shall ensure regular even discharge of the coke without cutting or shearing it.

(*b*) The rate of coke extraction must be easily adjustable by some simple device.

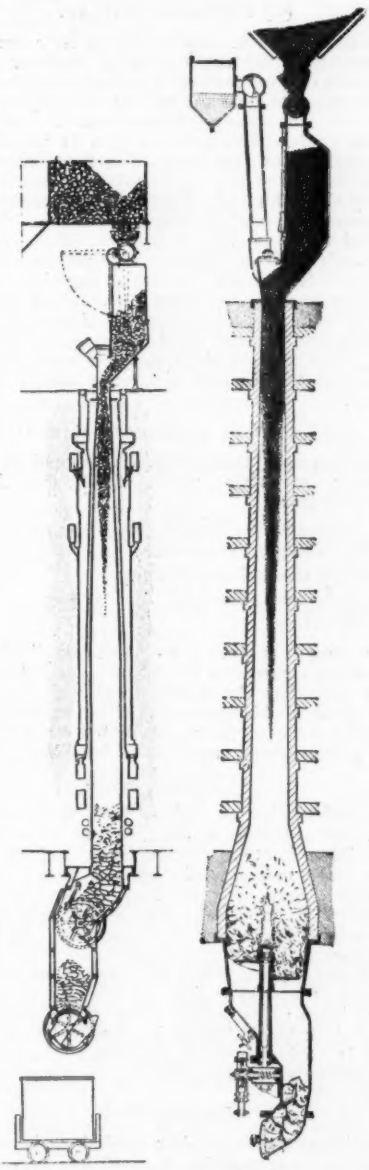
Satisfactory operation of the retort depends not only upon regular extraction of coke, but also upon regular feed of coal into the retort from the auxiliary hopper. In the design of top ironwork, the two main objects are:

(*a*) To ensure distribution of coal along the whole major axis length of the retort.

(*b*) To allow the gas to pass away with minimum contact with coal in the top ironwork.

#### (B) CORRECT TAPER.

Careful consideration has been necessary in determining the most suitable taper. The minor axis of the continuous vertical retort is tapered, with an increasing dimension towards the bottom, for two reasons:



Figs. 3 and 4.—Cross Sections through Minor Axes of Representative Vertical Retort Systems.

(*a*) To compensate for the swelling of the coal.

(*b*) To ensure easy travel of the charge as it passes down through the retort.

In determining the most suitable taper, a balance has been maintained between a number of factors.

(*a*) Carbonization takes place much more rapidly at points near the retort wall than at points farther away from the source of heat. Therefore, *under static conditions*, the rate of heat penetration to the centre of the charge is more rapid in a narrow retort.

(*b*) If through a retort of constant major-axis dimension and height, a given daily throughput

of gas must be obtained, it follows that the narrower the minor axis of the retort, the quicker the coal must travel, and therefore the less the time contact between the heating surface and any one piece of coal.

(*c*) Apart from any thermal considerations, the retort must operate with mechanical regularity on all coals with the minimum of rodding.

It is an interesting statement of fact that minor axis dimensions in the two leading systems of continuous vertical retorts are to-day approximately the same—namely :

| | |
|---|---|
| Top dimension . . . . . | 10 in. |
| Bottom ,, . . . . . | 18 ,, |

### (C) METHOD OF HEATING.

The continuous vertical retort is, in normal practice, heated by the combustion of producer gas and air, which can be controlled by two stages of combustion so as to give the zoning of temperatures as required. The zoning of the heats is variable for different coals. The producer gas is usually made in producers of the step-grate type operating on natural draught or slight pressure from steam-injected primary air. This type of producer reduces clinkering to a minimum, with consequent reduction in labour cost and increased life of linings. The combustion of producer gas and air may take place as the gases pass upwards through a series of superimposed horizontal combustion chambers surrounding the retort, or downwards through a number of vertical combustion chambers constructed along each side of the retort. The modern silica retort is safely used with an average temperature along the heated length of 1300° C.

### (D) CHOICE OF REFRACTORY MATERIALS.

It is necessary that the retorts should be built of refractory materials which fulfil the following characteristics :

(1) Resistance to high temperature.
(2) Resistance to abrasion.
(3) High thermal conductivity.
(4) Mechanical strength.
(5) Durability.

The large output per retort obtainable with present-day continuous vertical retorts is largely due to the fact that the heated length of the retort is constructed of highest-grade silica material. The top and bottom of the retort, which are subjected to lower temperatures, are built of hard-burnt firebrick.

### CAPITAL COST.

In consideration of various systems of carbonizing plant, capital cost is a factor of first importance. It is a striking fact that continuous vertical retorts show in a large majority of cases an actual saving in capital cost over any other form of carbonizing plant. The price of an installation is naturally influenced greatly by the size, and to a less extent by local circumstances. But to give some idea it may be stated that there are a number of installations being built at a cost of less than £250 per ton of coal carbonized per 24 hours; this price including the modern silica setting, heat insulation, and waste-heat boilers. This figure is no higher than the cost of the old fireclay settings erected twelve years ago without waste-heat boilers.

### LABOUR COST.

The labour costs are low, and show better figures per therm than machine-charged horizontals. From Mr. T. Hardie's figures ("GAS JOURNAL," April 6, 1927), the carbonizing wages work out at 0·221d. per therm with machine-charged horizontals making 72 therms per ton, and at 0·204d. per therm with continuous vertical retorts making 78 therms per ton.

### OUTPUT OF GAS PER SQUARE FOOT OF GROUND AREA.

In these days of increasing demand for gas, the problem of producing maximum output of gas from a given ground area is becoming a matter of increasingly great importance to gas engineers. Of all the forms of carbonizing plant, continuous vertical retorts give the largest output of gas per square foot of ground space occupied; and in this direction striking developments have been made within the past few years. In 1914 an approximate figure gave an output of 377 c.ft. of gas per sq. ft. of ground space per 24 hours.

In his Presidential Address to the Southern Association of Gas Engineers and Managers, 1927, Mr. Thomas Hardie gave the figures of 531 c.ft. and 600 c.ft. per 24 hours per sq. ft. of ground space in two recent installations of continuous vertical retorts. Still more recent figures show that the output of gas per square foot of ground space for such an installation may reach 800 c.ft. per day (see "GAS JOURNAL," Dec. 7, 1927, p. 684). These figures compare with 267 c.ft. per 24 hours per sq. ft. of ground area with modern machine-charged horizontal retorts in a house specially designed for the purpose (see "GAS JOURNAL," April 6, 1927, p. 34). Thus even in comparison with the most modern horizontal retort practice, vertical retort installations can produce nearly three times as much gas per square foot of ground space.

In very many instances this fact has enabled extensions to be made on existing sites, increasing the capacity by 100 p.ct. and over, and saving large expenditure for new sites.

There are several instances well known in the gas industry where gas undertakings, discussing the question of sites for entirely new works, have been able to abandon these expensive proposals, and by the concentration rendered possible by the continuously operated vertical retort have been able to effect very considerable economies in capital charges.

### MAINTENANCE.

The absence of complicated machinery, and the considerably less bulk of refractory work in proportion to capacity are reasons why maintenance costs are lower for continuous vertical than for horizontal retorts with machinery. The exact figure, however, depends upon so many factors, such as the particular coal carbonized, the type and efficiency of supervision, the working temperatures in the settings, and the calorific value of the gas produced, that it is very difficult to generalize on maintenance costs. Furthermore, maintenance costs per ton of coal carbonized will generally be low when the plant is operated at a capacity well below that of the greatest efficiency. We have, therefore, assumed in our calculation of production cost the figure of 10d. per ton of coal carbonized, which is a safe assumption within the experience of gas engineers operating continuous vertical retorts.

### GAS PRODUCTION COSTS.

From a consideration of the facts set out above, it is clear that continuous vertical retorts should be in a favourable position in comparison with any other form of carbonizing plant in the production of gas at a cheap rate per therm. This is borne out by the experience of many engineers.

(i.) The fuel cost is low.
(ii.) The capital cost is low.
(iii.) The labour cost is low.
(iv.) The maintenance cost is low.
(v.) The gas yield is high.
(vi.) The tar yield is high.

It may be taken as an average figure that the total net retort house cost of gas made in continuous vertical retorts, including carbonizing wages, capital charges, maintenance, and labour, is 1·75d. to 2d. per therm. In a number of cases actual costs lower than this are to be found. Confirmation of this figure may be obtained by means of the following calculation.

#### *Assumptions.*

1.—Price of coal on works, 27s. per ton.
2.—Average price of coke for sale, 27s. per ton.
3.—Tar yield, 11 gallons per ton†.
4.—Tar value, 4d. per gallon.
5.—Coke for sale, 11·2 cwt. per ton† (including breeze).
6.—Thermal yield of gas per ton of coal = 78†.
7.—Labour cost, 16d. per ton of coal*.
8.—Capital charges, £250 per ton of coal per day.
9.—Interest, &c., at 8 p.ct. per annum.
10.—Maintenance, 10d. per ton of coal carbonized.
11.—Working days per annum, 250.

* Hardie, "GAS JOURNAL," April 6, 1927.
† Hardie, "Fuel Economist," December, 1926.

#### *Total Cost per Ton of Coal Treated.*

| | d. | d. |
|---|---|---|
| Coal . . . . . | | 324 |
| *Less* Coke . . . . . | 181 | |
| Tar . . . . . | 44 | |
| | 225 | |
| Net coal . . . . . | | 99 |
| Capital charges . . . . . | | 20 |
| Maintenance . . . . . | | 10 |
| Labour . . . . . | | 16 |
| Total cost per ton . . . . . | | 145 |
| Net cost per therm . . . . . | | 1·86 |

### HEAT CONSERVATION.

From the thermal point of view, carbonization in a continuous vertical retort is a highly efficient process. This is due to a number of factors.

(i.) Heat interchange within the retort.
(ii.) Efficiency of step-grate producers.
(iii.) High conductivity of silica retorts.
(iv.) Installation of waste-heat boilers.
(v.) Heat insulation or heat recuperation.

In any carbonizing system the thermal treatment of the charge may be divided into three stages:

(i.) In which the temperature of each piece of coal is raised to that necessary for the evolution of gas.
(ii.) In which the temperature is maintained for a sufficient time for the whole of the gas to be driven off, during which stage the coal becomes coked.
(iii.) In which the temperature of the coke is reduced to that of the atmosphere. In the older systems this stage takes place outside the retort, and assumes the form of quenching by water, with a consequent waste of heat, as well as other inconveniences which will be dealt with later.

In the continuous vertical retort, carbonization is carried out with the minimum expenditure of heat. The cold coal entering at the top of the retort is progressively heated by the sensible heat from the gas passing up the retort. The coke at the bottom of the retort, after carbonization is complete, is cooled by means of steam and/or water within the retort; the sensible heat from the coke doing useful work through the medium of the steam to which the coke imparts its heat.

In assessing the thermal value of a process of carbonization, it is suggested that the figure that matters to the gas engineer is not the gross amount of fuel supplied to the producer, but the net amount —that is, the heat supplied to the producer *less* the heat value of the steam recovered from the waste gases. In the modern continuous vertical retort setting, 1500 lbs. of steam per ton of coal carbonized can be obtained. Assuming that under the best conditions of operation 8 lbs. of steam can be produced per lb. of coke in a direct-fired boiler, the 1500 lbs. of recovered steam is equivalent to at least 188 lbs. of dry coke. A high figure of coke charged to the producers may be taken as 336 lbs. per ton of coal carbonized. From this point of view the net fuel consumption may be regarded as no more than 6·6 lbs. of dry coke per 100 lbs. of coal carbonized.

Another factor which has contributed to the high thermal efficiency of modern continuous vertical retorts is the attention which has been paid to heat insulation or heat recuperation. In certain cases the secondary air for combustion is passed up within the outside walls of the setting, thus imparting to the air some of the heat which would otherwise be lost by radiation. In other cases the setting is surrounded by hollow blocks filled with slag wool, insulating bricks, or other insulating materials.

### QUALITY AND QUANTITY OF PRODUCTS.

(*a*) *Gas.*—In a number of characteristics, continuous vertical retort gas differs from the product from intermittent processes. Reference has already been made to the uniformity of the quality and yield of gas produced from continuous verticals; and the evident advantages accruing from this uniformity have been indicated.

It is now an established fact that gas made in continuous verticals never leads to troubles associated with naphthalene deposition. In addition, the gas from this type of plant contains a lower proportion of organic sulphur compounds; and this proves a distinct advantage in certain cases (or districts) where the maximum permissible sulphur content (apart from $H_2S$) in the gas is strictly limited.

(*b*) *Steaming.*—Continuous verticals make it possible, in a one-stage process, to increase greatly the yield of gas per ton of coal carbonized. By the introduction of steam at the base of the retort, water gas is made by interaction with red-hot coke. This water gas passing up the retort mixes with the coal gas which is being evolved from the coal in the upper parts of the retort, and a regular output of mixed gas is thus obtained from each retort.

As a considerable amount of data has already been published in connection with increased yields of gas and other products by steaming, it will be sufficient here to re-direct attention to the excellent summary of results of such tests in the Report of the Fuel Research Board for the period ended December, 1924, pp. 28, 29. Here are summarized the results of work carried out at the Fuel Research Station and at the Uddingston Gas-Works (Gas Investigation Committee of the Institution of Gas Engineers) on the steaming to various degrees of a large variety of coals, including several Durham coals and Lancashire, S. Wales, and Scotch coals.

(*c*) *Coke.*—Coke produced in continuous vertical retorts contains less moisture than that produced in systems in which water quenching is necessary. Consequently the calorific value of vertical retort coke is higher than that of horizontal or inclined retort coke. For this reason buyers who have had experience of both prefer "vertical" coke. Several instances of this can be cited.

No doubt this preference is masked by the fact that it is not in the interests of gas undertakings with both horizontal and vertical coke to dispose of to encourage any selection on the part of buyers.

Vertical retort coke, being drier and slightly less dense than horizontal retort coke, is easy to ignite; burns with low draught; and does not "spit" in the open fire.

The case for the continuous vertical retort as an economic coke-producing unit is well summed up by F. S. Townend in the following quotation from the recently published "British Fuel Problems," p. 398:

> It should be placed to the credit of the continuous vertical retort that it embodies a method of coke cooling which involves practically no capital outlay, eliminates nuisance, recovers the heat of the coke in a most valuable form—*i.e.*, of gas for distribution in the town—and provides a dry coke.

(*d*) *Tar.*—Vertical retort tar differs considerably from horizontal retort tar. A higher yield is always obtained in continuous vertical retort practice. The subject of the qualities and treatment of tars made by this type of plant was very fully discussed at the Tar Conference organized by the Joint Fuel Committee in 1926. It was shown on that occasion that vertical retort tar was of greater value per ton to the tar distiller than horizontal tar, due particularly to the greater yields of light oils and creosote. It was also shown that dehydration of vertical retort tar by suitable means leads to the production of a satisfactory road tar, which is already being used to a considerable and rapidly increasing extent.

(*e*) *Sulphate of Ammonia.*—The Fuel Research publication referred to above, as well as many others, show that steaming in continuous vertical retorts effects a considerable increase in the yield of sulphate of ammonia per ton of coal.

### FLEXIBILITY.

To the gas engineer, flexibility has three aspects:

(*a*) Output.
(*b*) Calorific value.
(*c*) Choice of coal.

From all these aspects the continuous vertical retort proves a particularly suitable system.

(*a*) In comparison with other forms of carbonizing plant, the continuous system is particularly sensitive to demands of output. Within reasonable limits, throughput may be speeded up, with consequent increase in output of gas, and, conversely, by the simple operation of reducing the extractor speed, the output of a plant may be slowed-down within a few hours. It may be claimed that with intermittent systems this can be effected by altering carbonizing time. This is quite true, but such alteration involves alteration to a schedule of duties, and generally far more disturbance of routine than a mere mechanical regulation, which is all that is required with the continuous system.

(*b*) The calorific value of gas may be readily and quickly varied by altering the percentage of steaming. At the present day, installations are working with equal success making 525 to 400 B.Th.U. gas.

(*c*) As regards choice of coal, the modern continuous vertical retort can operate successfully on any type of coal. There is a tendency to believe that this type of plant requires specially selected coals. It is certainly a fact that continuous vertical retorts show selectivity as regards performance with various coals to a greater degree than static types of plant, but that does not alter their capability of treating all classes of coal.

(*d*) On the other hand, selection of coals in horizontal retorts and intermittent systems generally is of much less value from the point of view of thermal

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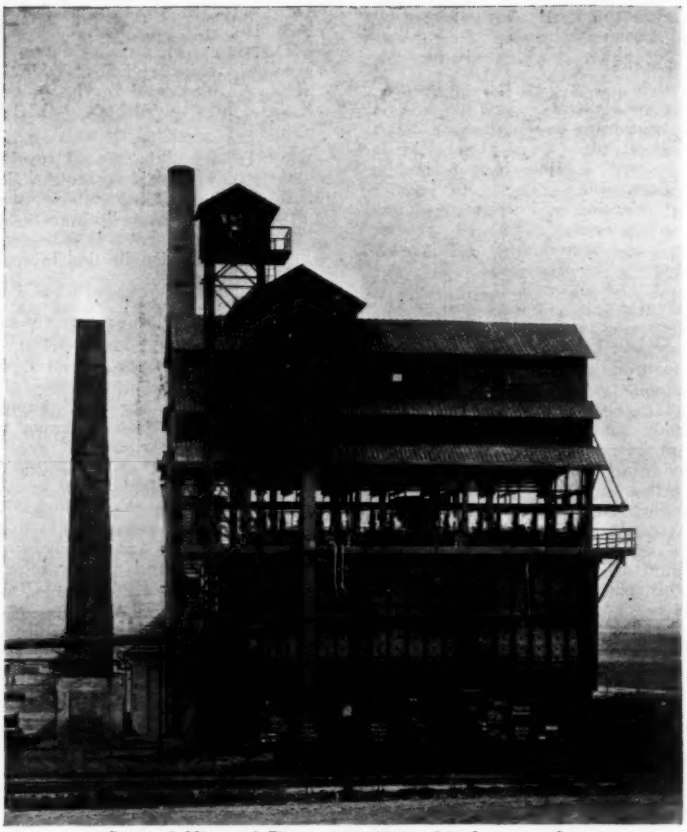

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General View of Plant, 650,000 cubic feet per day.

## Some Advantages of VERTICAL INTERMITTENT CHAMBER OVENS

**For advantages 1 and 2 see previous issues.**

**3** By steaming the charge, and the consequent production of water-gas, not only can gas of any calorific value be produced, but the maximum thermal gas production is obtained without the employment of separate water-gas plant.

**4** The steaming being carried out at the end of the carbonizing period, when the mass of coke has reached its highest temperature, the water-gas is produced under ideal conditions, and is of very high calorific value, containing only a small percentage of $CO_2$.

FOR FURTHER ADVANTAGES SEE SUBSEQUENT ISSUES.

***INTERMITTENT VERTICAL CHAMBER OVENS are now under construction for:—***

*The Wandsworth, Wimbledon, & Epsom Gas Co. - - (Capacity) 180 tons/day*

*The Gas Light and Coke Company - - - - - ,, 380 ,,*

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output per ton than in continuous vertical retorts. That is to say, when making gas of a given calorific value, a much smaller increase in yield is obtainable by selecting coals for carbonizing in horizontal retorts than in continuous vertical retorts, particularly when calorific values of 500 B.Th.U. and less are in question.

There is also a certain amount of belief that continuous vertical retorts are only suitable for big works. This is not a statement of fact, as some of the best results and greatest savings are effected on small undertakings. At the present time there are at least nine plants making 150,000 c.ft. per day or less, while there are at least three plants making over 15 million c.ft. of gas per day, each within a single house.

### Working Conditions and Cleanliness.

From the point of view of the men working on the plant, continuous vertical retorts give better conditions than does any other form of carbonizing plant. Manual labour is reduced to a minimum by reason of the fact that once the coal is elevated to the overhead bunkers, advantage is taken of gravity until the coke is removed from the retort house. The employment of heat insulation on the plant, in addition to reducing the fuel bill, improves the working conditions. There is no smoke during charging—a factor inevitable with every other form of carbonizing plant—nor is there any of the steam and "smother" associated with the quenching of hot coke in all but the most modern static types of plant. This absence of steam from quenching causes less deterioration of structural steelwork. Quite apart from these advantages, the smallness of the space occupied by the vertical retort installation makes it easier to keep clean.

It is perhaps worth recording that the operation of vertical retorts is so simple that unskilled labour is being regularly trained to perform the necessary work within a week or two. Thus the management of a works is placed in a position of comparative independence, owing both to this fact and to the fact that the number of men required for the operation of a plant of given capacity is greatly reduced.

### Local Amenities.

Reference has been made to the fact that continuous systems of carbonization in vertical retorts are characterized by an entire absence of the clouds of smoke and steam which are the necessary accompaniment of charging and discharging operations in horizontal or inclined retorts, coke ovens, and other intermittent systems. For this reason it is possible to instal continuous vertical retorts in situations where strong objection would be raised to intermittent systems. In several instances vertical retorts have for this reason alone been adopted by the gas undertakings of seaside resorts and inland holiday and residential towns.

### Conclusion.

A gas engineer faced with the problem of extending or replacing his carbonizing plant has many factors to consider. To one engineer ground space may be of supreme importance. In another case gas quality may be the determining factor. Local circumstances alter the requirements, but the adaptability of carbonization in continuous vertical retorts is proved by the fact that a large portion of the gas in nearly 200 towns in Great Britain is now made in plants on this principle—a notable tribute to what may reasonably be regarded as the outstanding development in twentieth-century methods of gas manufacture.

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**Paper E. Session I.**

# Vertical Intermittent Chamber Ovens for Gas Manufacture.

**By N. J. BOWATER, O.B.E., B.Sc., Assoc.M.Inst.C.E.**

**Abstract.**

In a valuable paper read before this Institution in December, 1926, by Mr. Thomas Hardie, M.Inst.C.E., on "Some Phases of Modern Practice in Gas Manufacture," an illuminating insight was provided into the progress that has taken place in carbonizing practice, both with horizontal retorts and with continuous vertical retorts, during recent years. The object of the author of this paper is to supplement the above information by giving the Institute particulars of the recent developments that have taken place on the Continent in the vertical intermittent chamber oven process of carbonization.

The introduction into this country of the intermittent vertical system just before the war was interrupted by the outbreak of hostilities; and it is only comparatively recently that interest has again been aroused in the matter. The absence of further developments in this country during the war is understandable, as not only were most English gas-works contractors not interested in the intermittent chamber oven or retort system, but they were definitely interested in other types of carbonizing plants, such as horizontal retorts and continuous vertical retorts, while the stress of the war conditions, and the special calls made upon them, naturally rendered gas engineers, of necessity ignorant of the developments being made on the Continent, disinclined to go in for new developments of this kind.

In Germany, however, the intermittent vertical chamber ovens continued, and continue, to progress, not only for small gas-works, but for large installations; and the reason for their adoption is more readily understandable when the advantages of the system are considered. In view of the re-awakened interest in this country, some of these advantages may be briefly enumerated as follows:

(1) The coal is charged into the chambers from a simple container, by means of gravity, and is similarly discharged, thus doing away with the charging and coke pushing apparatus associated with horizontal retorts or ovens, and the continuous feed and mechanical coke extractors associated with continuous vertical retorts.

(2) The coal during carbonization lies quiescent in the chamber as in horizontal retorts, and is not subjected to the continuous movement that occurs in continuous vertical retorts; the result being the formation of a strong coke (from any reasonably caking coal) and only an extremely small proportion of breeze. As will be seen later on, in Table I., this proportion of breeze is practically negligible with a good caking coal.

(3) Owing to the conditions described in (2), the choice of coals for the intermittent vertical chamber ovens is very much wider than for continuous vertical retorts, and any coal suitable for horizontal retorts is suitable for vertical chamber ovens. The advantage of this factor is not only one of convenience, but is also frequently of considerable financial importance to a gas undertaking.

(4) Steaming of the coal in the vertical intermittent chambers may be accomplished as in continuous vertical retorts, thus permitting a high gaseous therm production per ton of coal without the employment of water gas plant.

(5) The ground space occupied per ton carbonized and per therm of gas yield is very low, probably as low as with continuous verticals, and much lower than with horizontals; one ton of coal carbonized per day per 20 sq. ft. of ground space occupied being obtained with intermittent vertical chambers.

(6) The carbonizing period can be varied according to the gas requirements from about 12 hours upwards; and by suitable timing of the charging and discharging the whole of the carbonizing labour can be reduced to two 8-hour shifts per day, there being, of course, during the 24 hours one 8-hour or two 4-hour periods when no carbonizing labour need be present.

(7) As the corollary of (1) and (6), the labour costs are low. Furthermore, even during the 8-hour shifts only one man is required for coal charging and one man for coke discharging for a chamber bench having a capacity of up to 120 tons for 24 hours, while there is no continuously operating machinery requiring attention.

(8) Maintenance costs are extremely low; there being neither expensive mechanical coal charging machines nor coke extractors. Consequently the risk of breakdown of machinery is also reduced. High combustion chamber temperatures and quick heat transmission are obtained by the employment of silica refractories; while, owing to there being no movement of the coke in the retort until it is finally discharged, and the final movement being a vertical one, the wear and tear on the retort walls is considerably less than with horizontal and continuous vertical retorts.

(9) The vertical chamber ovens lend themselves to the widest variation in individual capacity to suit the different operating conditions and the capacity of the carbonizing plant as a whole. The ovens are built in sizes of from 1 to 7·5 tons capacity, and can be grouped in their settings as desired.

The modern intermittent chamber oven is so constructed that the coal rests in the form of a tapered slab on end, from 12 to 16 ft. high. Other dimensions depend on oven capacity, and coal thickness upon the time of carbonization required. For example, a chamber having a capacity of 2·5 tons per charge, or 5 tons per day with 12-hour charges, would be approximately 11 in. in width, 9 ft. 6 in. in length, and 15 ft. in height. A number of these would be grouped together side by side in a common setting, with the necessary heating flues and with its own recuperator or regenerator for preheating the air or air and producer gas, as the case may be, according to whether the chambers are heated by hot gas generated in producers built into the setting, or by cold, clean gas generated by outside producers.

A number of these settings are then grouped together, braced and tied by means of suitable buckstays, &c., and form a bench or battery along which run the common mains for foul gas, tar, heating gas, and steam.

Gas off-take pipes are provided, of course, for each chamber, and are connected, preferably, with separate hydraulic seal pots for enabling each chamber to be isolated from the common foul gas main when discharging and recharging; the gas off-take pipes being also continually sprayed in the more modern installations to avoid any possibility of blockage.

The charging is done by means of a coal bus, which loads from an overhead bunker and runs along the whole bench of chambers. The bus holds sufficient coal for completely charging a chamber, as well as sufficient coke breeze for filling up the bottom of the chamber. The first movement of the charging lever usually opens up the breeze hopper; the continued movement of the lever then opening the coal hopper.

Steaming is usually carried out during the last few hours of the carbonizing period; the amount depending upon the ultimate calorific value of the gas required.

Carbonizing temperatures are, of course, similar to English practice, and silica refractories are now universally employed for the chamber itself and the combustion chambers.

Intermittent vertical chambers may be heated, as explained, by means of self-contained producers, gasifying the coke as produced, or by means of independent producers—*i.e.*, by the cold, dust-free gas generated in such independent producers gasifying coke breeze or even bituminous slack.

When self-contained producers are employed, hot flue gases are available for steam raising; but when independent producer gas is utilized for heating the bench, the flue gases, as already explained, usually only suffice for hot water generation.

In larger installations—say, over 50 tons per day—material financial advantages can be shown in favour of the outside producer method of heating, partly due to the possibility of their utilizing low-value fuel, where such is available, and partly due to the improved operating conditions and longer life of the setting. The uniformity of heating by means of clean producer gas is very marked as compared with the heating by means of self-contained producers, where irregularities in the quality of the gas, &c., are inevitable, owing to the intermittent nature of the clinkering operations.

The gas and air for combustion are easily and exactly controlled by means of ordinary hand-operated metal valves, whereas with built-in producers (the gas and air being controlled by dampers) no such accuracy is obtainable. Furthermore, the dust-free gas not only assists in this regularity of heating, but ensures a long life to the ovens and a continued efficiency of heat transfer to the coal charge, owing to the absence of dust in the combustion chambers and flues.

The heat required for carbonization in the form of cold, clean producer gas is in the neighbourhood of 25 therms per ton—dependent, of course, upon the calorific value of the distillation gas (that is to say, upon the steaming required and the moisture in the coal).

Table I. is appended as an example of what can be done with an installation of intermittent vertical chamber ovens when carbonizing a Durham coal (Londonderry) in a small setting of seven chambers having a capacity of approximately 2 tons of coal each; the setting being provided in this case with self-contained producers.

TABLE I.

| | | |
|---|---|---|
| Gas produced per ton of coal carbonized | | 15,480 c.ft. |
| Calorific value of gas at 60° Fahr. and 30 in. Hg. | | 537 B.Th.U. per c.ft. |
| Therms per ton | | 83·2 |
| Analysis of coal— | | |
| Moisture | 1·08 p.ct. | |
| Ash | 8 60 ,, | |
| Volatile | 31·48 ,, | |
| Fuel consumption | 14·1 ,, | 2·82 cwt. per ton carbonized |
| Saleable coke—*i.e.*, $\frac{\text{Coke over } \frac{3}{4} \text{ in.}}{\text{Coke produced}}$ | | 99·5 p.ct. |
| Waste heat recovery possible from flue gas leaving setting at 650° C. | | 700 lbs. per ton carbonized |
| Waste heat recovery possible from dry cooling of coke | | 700 lbs. per ton carbonized |

These results, obtained under normal everyday operating conditions, are, the author believes, superior to any that have been obtained in other types of carbonizing plant.

**Paper F. Session I.**

# Intermittent Vertical Chambers.

**By R. H. RUTHVEN.**

To-day the gas engineer has a very wide choice of plant for the manufacture of coal gas. Five systems are available—namely, horizontal retorts, intermittent vertical chambers, inclined chambers, horizontal chambers or coke ovens, and continuous vertical retorts. It is not proposed to discuss the relative merits of these different types, but rather to offer for your consideration the experiences over the past eighteen months with an installation of intermittent vertical chambers at the Ramsgate Corporation Gas-Works.

### HISTORICAL NOTE.

The intermittent vertical chamber as built at Ramsgate is the modern form of the intermittent vertical retort, reintroduced by Dr. Bueb in 1902 to 1904 after several unsuccessful attempts had been made previously to evolve a vertical retort. The earliest vertical retort dates from as far back as 1828.

Dr. Bueb's retort of 1904 was developed during the succeeding years under the well-known name of the Dessau retort, and, as such, has been built in large numbers on the Continent and in other parts of the world.

It was introduced into England in 1909, when the plant at the Ayres Quay Works of the Sunderland Gas Company was built. Subsequently plants at Hull, Ossett, Taunton, &c., were erected. The standard dimensions of these retorts were 13 ft. 1½ in. in height and of oval cross-section tapering from 9 in. by 22½ in. at the top to 13¾ in. by 27¼ in.

at the bottom. The retorts were set vertically in two or three rows, and each retort carbonized about 9 cwt. of coal in 12 hours. The retorts were built of fireclay material; the lower half generally being built-up of segmental blocks and the upper half being one moulded section. The two or three retorts were treated as one unit, as they were provided with one common gas offtake, were charged and discharged simultaneously, and were heated by the same stream of heating gases.

As built in this form, intermittent vertical retort installations met the purpose for which they were originally conceived—namely, to give an increased make per ton of coal carbonized, and an increased yield of gas per unit of ground space, and (by making use of gravity for charging the coal and discharging the coke) to effect a reduction in labour cost.

Since the war, competing types of gas-making plant have made considerable progress, which may be summed up as the improvement of gas output per ton of coal per unit of ground space and per man employed; and a corresponding improvement in the performance of the intermittent vertical retort was necessitated.

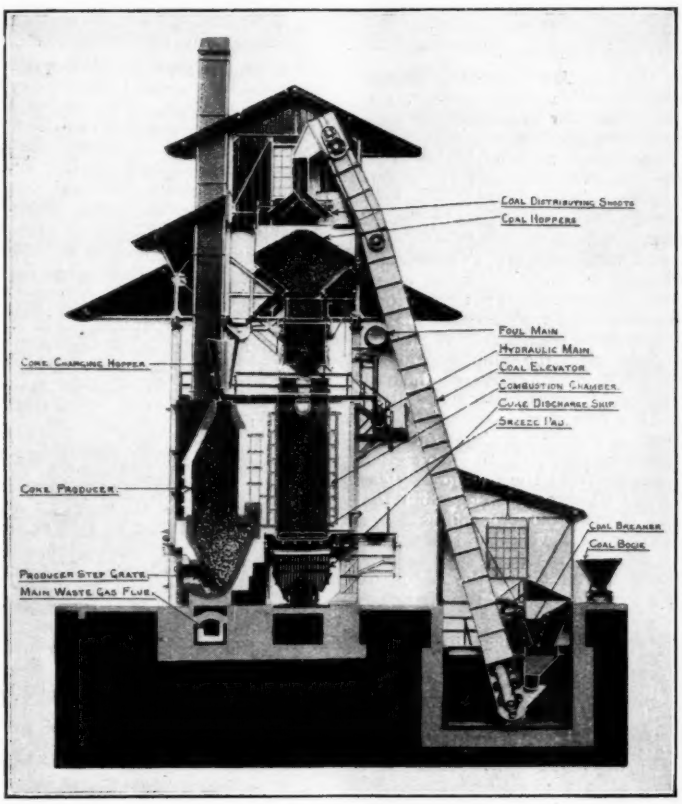


**Fig. 1.—Model of W-D Intermittent Vertical Chamber.**

This has been effected by two main improvements. While the general form of the setting itself has been maintained, one large chamber which may have a capacity of 2¼ to 5 tons has been substituted for the three retorts operated as one unit. Secondly, the employment of silica material has enabled a quicker rate of carbonization to be obtained, and thus a larger throughput of coal per day has resulted when making a high quality of gas, or, alternatively, an extension of the time available for steaming, thus gaining an increased thermal yield of gas of a lower calorific value per ton of coal. These points will be elaborated in a later section; and it will now be well to give a description of the installation at Ramsgate, which is the first example in this country of the modern intermittent vertical chamber.

### DESCRIPTION OF INTERMITTENT VERTICAL CHAMBER PLANT.

The chambers themselves in cross-section are of approximately rectangular form with rounded corners and sides slightly cambered. The dimensions at the bottom are 8 ft. 1½ in. major axis by 12⅝ in. mean minor axis. The corresponding dimensions at the top are 3 in. less; there being a uniform taper from top to bottom. The over-all height is 16 ft. 8 in. There are 15 such chambers set side by side in four beds; two comprising five chambers, and the other two containing three and two chambers respectively. The normal charge of coal is 2·25 tons carbonized in 12 hours; and hence the normal carbonizing capacity is 67·5 tons per day.

The chambers are supported on a bed formed by cast-iron plates resting on setting steelwork. The bottom doors of the chambers are bolted to the underside of these cast-iron plates. A course of fireclay blocks rests on the plates, these forming the insulation. The chambers and heating flues above this are all built in highest grade silica material containing not less than 95 p.ct. of $SiO_2$. The top of the chamber is formed of fireclay blocks in which provision is made for three charging openings at the top and the gas offtake at the side. A light iron framework carries the three top charging doors, which are fitted with the usual eccentric closing levers.

Each bed is provided with a step-grate producer (Woodall-Duckham pattern); and the heating gases, after passing from the top heating flue, descend through a recuperator, thereby pre-heating the secondary air. In the five chamber beds the recuperator is in two halves situated on either side of the producer, and, in the case of the three and two chamber beds, is situated on one side of the producer only. The waste gases are collected in a common waste gas flue running the length of the bench beneath the producers, and pass thence through a waste-heat boiler, or, when this is down for inspection, direct to the chimney. Fig. 1 shows a sectional view of a W-D intermittent vertical chamber.

### METHOD OF HEATING.

The producer gas enters the bottom heating flues, where it meets a primary supply of secondary air which has been pre-heated while ascending the recuperators and descending again between the chamber and producer block. Preliminary combustion takes place round the lower 4 ft. of the chamber. As the heating gases rise, an auxiliary supply of secondary air is introduced at a point about 4 ft. up. Combustion is thus completed, and the hot gases make their way to the top of the chambers more or less backwards and forwards along horizontal heating flues. The heating gases pass from the top heating flue to the top of the recuperators as mentioned before. A series of dampers is provided in the

floors of the horizontal heating flues, which enable the heating gases to heat uniformly the chamber wall from back to front. The temperature gradient between the bottom and the top heating flues is arranged so that all portions of the charge are carbonized at the same time.

### GAS OFFTAKE, &c.

The gas passes from the top of the chamber, through an offtake pipe sloping slightly downwards from the chamber to a seal pot, and thence upwards to the collecting main. Each chamber has its own individual seal pot. A liquor spray is placed in the sloping offtake pipe, which by cooling the gas keeps the pipe clean. No augering is required. A second spray is fitted in the uptake pipe just below the point where it joins the collecting main. This serves to cool the gas further, and provides an increased amount of liquor for flushing out the seal pot. When the chamber is in course of carbonizing, the gas can pass freely through the seal pot; the level of the liquor being kept low by the tar overflow. When sealing up for discharging, a sleeve is dropped into the overflow. The liquor from the sprays builds up in a few seconds and overflows at the top of the sleeve, thus sealing off a curtain plate which separates the gas offtake from the uptake.

### CHARGING THE CHAMBERS.

Let us assume that the chamber is empty. A pad of breeze is first dropped on the bottom door, for the purpose of keeping the door cool and for preventing the coal lying below the bottom combustion chamber, and thus remaining uncarbonized. The measured coal charge is then dropped on to the breeze, the top doors are closed, and the seal is lowered so that the gas has an uninterrupted passage to the collecting main.

For conveying the coal and breeze from the storage hoppers above the bench, a charging machine is provided. This has two compartments; a small one holding sufficient breeze for one chamber, and a large one holding sufficient coal for one charge. When the charging machine arrives over the chamber to be charged, a light framework is dropped over the top charged openings. This framework carries two hoppers which rest in the two outside openings and a hood which fits over the centre opening and connects with a ventpipe carried by the charging machine on the side remote from the operator. The breeze is dropped through all three openings, but the coal is dropped through the two outer openings only; the centre one functioning as a vent for the smoke and dust which pass through the hood and up the chimney, being discharged well above the heads of the operators. Fig. 2 gives a view of the charging level at Ramsgate.

### DISCHARGING THE CHAMBER.

The sleeve having been dropped into the tar and liquor outlet of the seal pot, the liquor from the sprays builds up in a few seconds, and seals off the chamber to be discharged. The top doors are then opened. The hot coke skip is run into position under the chamber. For opening the doors, a double hydraulic ram is fitted to each bed. This moves a rack which extends the length of five chambers backwards and forwards horizontally. By a pinion wheel and clutch, the movement of this rack is communicated to the shafts carrying the bottom doors. If a key is inserted in any particular clutch, the rack will operate one door; the other pinions running loose. After the weight of the door has been taken by the hydraulic pressure, the catches are removed from the door. The pressure control lever is thrown over, and the bottom door swings open and the hot coke drops from the chamber. The pressure control lever is thrown back again, and the rack closes the door. After putting on the catches, the eccentrics can be tightened up and the clutch released by taking out the key, which is transferred to the chamber next to be discharged. In the meantime, the coke skip is traversed to the quenching tower by an electrically operated rope haulage system. Fig. 3 is a view of the discharging level at Ramsgate.

### QUENCHING.

The quenching is carried out under a tower composed of a light steel framework carrying asbestos sheets and resting on a concrete base. At the base of the tower, and just above the top of the coke skip, are a number of spray pipes. A water tank is provided above the chamber bench; this supplying the sprays by means of a syphon arrangement which delivers a fixed amount of water per quench.

After being quenched, the coke is dropped from the skip into a hopper, whence it is taken to the screening plant by an automatic inclined skip hoist.

### COAL HANDLING, &c.

The supplies of coal, coke to producers, and breeze from the chambers are elevated to the storage hoppers above the chambers by a gravity bucket conveyor (lip-bucket type). This same elevator will put coal into store and also draw coal from the store.

### CHOICE OF CARBONIZING PLANT.

In determining the suitability of any particular carbonizing plant for his individual circumstances, the gas engineer must take into account (among others) the following factors:

(1) Applicability to the site available.
(2) Suitability for carbonizing the coals which give the least net cost of coal per therm.
(3) Maintenance costs.
(4) Labour costs.
(5) Yield of therms at any desired calorific value.
(6) Variation in calorific value as desired.
(7) Flexibility as regards output.
(8) Quality of the coke.
(9) Absence of the troubles associated with pitch, naphthalene, &c.
(10) Ease of management and general amenity of the plant.

It is proposed to discuss the performance of the intermittent vertical chamber type of plant under the above headings. The author has the advantage of using the results obtained in a series of tests under various conditions carried out in conjunction with the builders of the plant (the Woodall-Duckham Company) during the last few months. The plant has now been working for eighteen months; and the results may therefore be taken as those obtained after the plant has been thoroughly seasoned.

### APPLICABILITY TO THE SITE AVAILABLE.

This generally resolves itself into a question of ground space required. The Ramsgate plant has a nominal carbonizing capacity of 67·5 tons per day when operating on 12-hour carbonizing time. No difficulty is experienced in maintaining this throughput. Under such conditions the ground space occupied by the bench and producers is 18·6 sq. ft. per ton of coal carbonized per day. Actually, *including waste-heat boiler, chimney, and quenching tower*, the plant is occupying a length of 72 ft. in a retort house 41 ft. wide, or an area of 2952 sq. ft. This is equivalent to 43·7 sq. ft. per ton of coal per day. The author understands that more recent plants have been built with chamber capacities 50 p.ct. greater on a ground space very little larger than that required by the Ramsgate plant, and thus the area per ton of coal per day required by such a plant would be much lower than that quoted above.

The Ramsgate plant is situated within the walls of an old retort house, the height of which was increased about 8 ft. 4 in. with a further extension upwards to house the coal storage hopper.

### SUITABILITY FOR CARBONIZING ALL CLASSES OF COAL.

Carmichael (Inst.Gas Eng., 1927) has shown that the net cost of coal mainly depends on the cost of the coal carbonized. The coals normally carbonized at Ramsgate are Durham unscreened second quality coals and Kent slack. All these are strongly swelling coals. In only one case—one of the Kent coals—has the vertical chamber plant failed to discharge the coke. Below are given the gradings of some of the coals used in the chambers.

*Grading of Coals Used.*

| — | S. Yorkshire Coal. | Durham. | Durham. |
|---|---|---|---|
| | P.Ct. | P.Ct. | P.Ct. |
| Above ½ in. . . . . | 61·5 | 54·6 | 42 |
| Below ½ in. . . . . | 38·5 | 45·4 | 58 |

It is felt that any plant that can deal successfully with coals of this description and grading can be considered suitable for most coals normally used in gas manufacture.

### MAINTENANCE COSTS.

It is naturally too early at this stage to give any figures for this item. So far there is no sign that any cost will be incurred under this heading for a considerable period. This bears out the experience gained on the Continent over a number of years with similar installations of vertical chambers built of

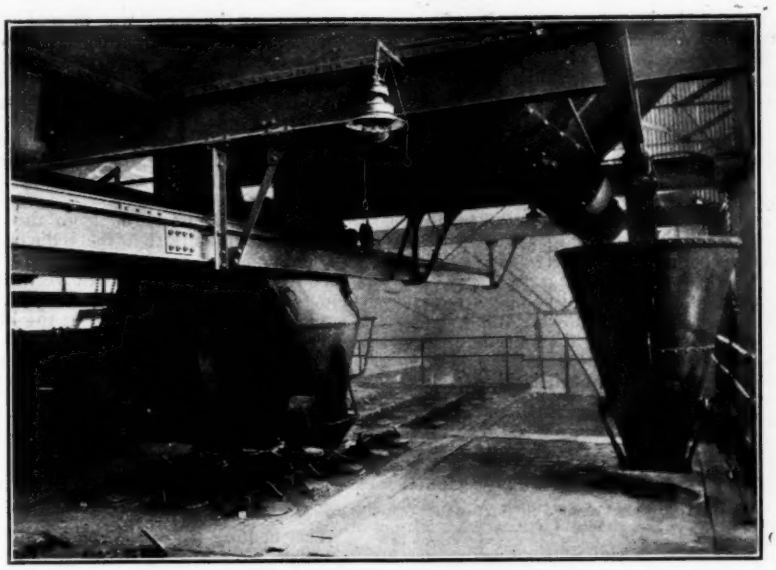

Fig. 2.—Top of Setting Level, Ramsgate.

silica material. The use of high-grade silica should ensure this. The advantages of silica (in the construction of vertical chambers) are several. Primarily owing to its higher conductivity, and also to the fact that high temperatures (1400° to 1450° C.) can be carried with safety, its use permits of rapid rates of carbonization. In addition, it appears to be resistant to the attacks of "salt" in coals—a matter of importance with coals from some sources. The reputed disadvantages of silica—namely, its expansion during heating and its tendency to spall under fluctuating temperatures below about 580° C.—are not such as to cause trouble in the case of vertical chambers. Expansion is looked after by the provision of expansion joints during construction. The vertical construction of the setting is such that it can be arranged to expand upwards as a monolith, thereby avoiding horizontal shearing movements. Once the settings are brought up to carbonizing temperature, the silica work is always maintained at temperatures well above those at which spalling is possible. The known success of silica construction in coke ovens should be repeated with silica construction in intermittent vertical chambers.

### Labour Costs.

The Ramsgate plant is run by six men per day who carbonize 11·25 tons of coal per man per day. At 75 therms per ton, this is equivalent to 844 therms per man per day. In addition to charging and discharging, the same six men attend to producers, seal pots, pipe cleaning, and keeping the plant clean. It would be possible to exceed this figure on larger plants and with chambers of a larger capacity.

### Yield of Therms and Flexibility of Plant.

The introduction of the Gas Regulation Act of 1920 has necessitated a new technique in town gas manufacture in so far as the gas engineer has the choice of two methods of producing a gas of a calorific value of (say) 520 B.Th.U. downwards—namely, either by producing a high calorific value of gas in the carbonizing plant and diluting with water gas, or producing gas of the required quality direct by steaming the retorts or chambers.

It is generally the practice at Ramsgate to produce the quality required—namely, 500 B.Th.U.—by steaming; but on occasion, in order to balance coke stocks, a high-quality gas is made in the vertical chambers, and the dilution is carried out by lightly carburetted water gas.

Soon after the intermittent vertical type of plant was introduced in 1904, its suitability for increasing the yield of gaseous therms by steaming was discovered. Dr. Davidson ("Journal of Gas Lighting," 1912, Vols. 117 and 118) showed that after the charge in intermittent verticals had given off its volatile matter, and the coke was at a temperature of 900° C. and upwards, the introduction of steam over as long as 4 to 5 hours resulted in the production of considerable quantities of good-quality water gas.

In actual practice we find at Ramsgate that with combustion flue temperatures high enough, there is a good production of water gas; the thermal yield per ton of coal being appreciably increased.

In Table A you will find the results obtained with several classes of Durham, Yorkshire, and Kent coals. The yields of gas per ton of coal as charged are given in the table, and they are here summarized after conversion on to the common basis of 6 p.ct. of ash and 2 p.ct. moisture.

| | | | C.Ft. per Ton. | Therm per Ton |
|---|---|---|---|---|
| 1. | Durham A | (12-hr. work) making 518 C.V. | 15,200 | 78·8 |
| 2. | ,, B | (15-hr. work) ,, 516 ,, | 15,100 | 77·9 |
| 3. | ,, C | (15-hr. work) ,, 477 ,, | 17,770 | 84·8 |
| 4. | S. Yorks. | (15-hr. work) ,, 505 ,, | 15,710 | 79·3 |
| 5. | Kent | (15-hr. work) ,, 521 ,, | 13,300 | 69·3 |
| 6. | ,, | (15-hr. work) ,, 490 ,, | 14,740 | 72·2 |

Probably the most interesting of the above tests are the production of a gas of 477 C.V. from the Durham C., which naturally yields a rich gas under straight coal gas conditions, and the results with a Kent coal on which very little information as to carbonizing capabilities is available.

The Kent coal contains about 28 p.ct. of volatile matter, and cannot be considered a very good gas-

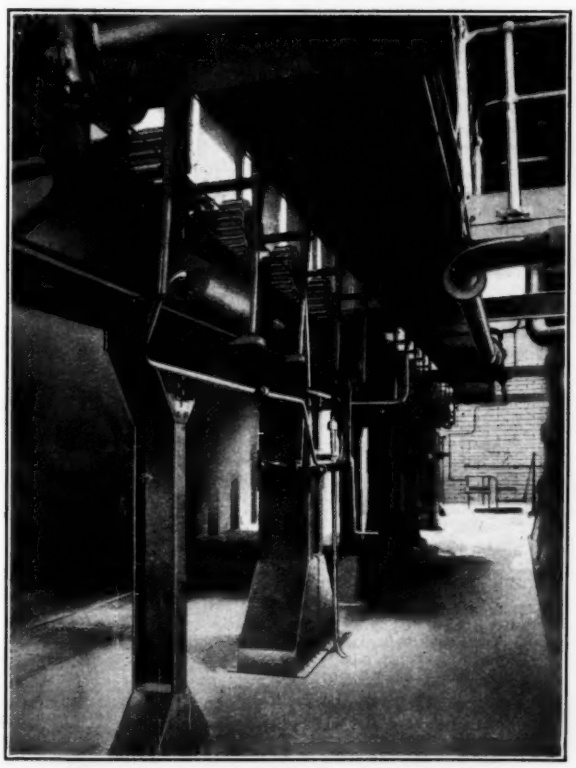

Fig. 3.—Floor Level of the Chamber House, Ramsgate.

making coal, as its yield is only 12,200 c.ft. of 521 C.V. gas, or 63·6 therms per ton as charged. This low result is due in part to the comparatively high ash content (12 p.ct.) in the fine slack coal. At present it is an economic proposition to use this coal at Ramsgate, as its lower yield of gas is offset by the saving in freightage as against Durham coals. This year about one-third of coal carbonized at Ramsgate has been Kent slack coal.

The flexibility in gas production of any carbonizing plant is of paramount importance. It is the practice at Ramsgate to vary the output of gas by reducing or increasing the carbonizing time between 12 hours and 18 hours.

As an illustration of what flexibility in gas output is possible, the figures in the following table have been compiled. In the first line the output of the 15 chambers at Ramsgate, when using two-thirds Durham coal and one-third Kent coal, is given. The calorific value of this gas is 506. In the second line is given the gas output with 100 p.ct. Durham coals making a 477 C.V. gas.

*Daily Output of Gas (with the Whole Plant at Work).*

(Volumes and Calorific Values at 60° Fahr. and 30 In.)

| Coal. | Calorific Value, B.Th.U. per C.Ft. | Carbonizing Time. | | | |
|---|---|---|---|---|---|
| | | 12-Hour. | 14-Hour. | 16-Hour. | 18-Hour |
| ⅔ Durham . . . | 506 | C.Ft. 949,000 Therms. | C.Ft. 814,000 Therms. | C.Ft. 712,000 Therms | C.Ft. 634,000 Therms. |
| ⅓ Kent . . . . | | 4,800 | 4,120 | 3,600 | 3,200 |
| 100 p.ct. Durham . | 477 | C.Ft. .. Therms. .. | C.Ft. 988,000 Therms. 4,720 | C.Ft. 865,000 Therms. 4,120 | C.Ft. 768,000 Therms. 3,690 |

Varying the carbonizing time as above suffices for all the fluctuations met with throughout the year.

### COKE QUALITY.

As may be judged from the fact that the coal is carbonized in a confined space, the coke, especially from the lower volatile coals used, such as second quality Durham and Kent coal, is hard and close pored. It is very suitable when graded for coke boilers, closed stoves, bakers' ovens, boilers, &c. It undoubtedly lacks the freer burning properties of some horizontal or continuous vertical coke for open grates, but has advantage over the latter in coke boilers and closed stoves in that they hold a greater weight of combustible matter when full—which fact, in conjunction with its rather slower burning properties, makes one firing last longer.

### ABSENCE OF PITCH AND NAPHTHALENE TROUBLE.

When the plant was first started, considerable trouble was experienced with pitch in the seal pots, offtake pipe, and main to the governor. Investigation showed that the temperature of the gas entering the seal pot was much higher than was anticipated, pointing to the fact that the sprays in the offtake were not working properly, and were not cooling the gas to a sufficient degree to avoid the distillation of the tar deposited in the seal pots, &c. It was found that the spray was not correctly adjusted. As soon as the spray was altered to give the correct shape of cone and a rather larger volume of liquor, the trouble ceased; and there has been no recurrence. It is, of course, an important point of supervision to keep the sprays functioning properly. This is mainly a matter of regular inspection of the sprays in the offtakes once per day when the pipes are cleaned out, and attending to any spray not operating correctly. It is essential that clean liquor should be supplied to the sprays.

It is difficult to argue from the number of naphthalene complaints that the reduction in number experienced is due to the small amount of naphthalene produced by the intermittent vertical chamber plant. Our tests show that there are about 4 grains of naphthalene in the coal gas at the inlet to the station meters. That the amount is likely to be low may be expected from the fact that the chambers are practically filled and the gas leaves the charge at the point where the temperature of the walls is lowest, and has little chance of being long in contact with hot brickwork; and this is borne out by the fact that the free carbon in the tar is low (approx. 6 p.ct.).

### EASE OF MANAGEMENT, &C.

The heating is in charge of the works chemist. Control is mainly by varying the pull in the main flue by the fan damper on the waste-heat boiler, and altering the secondary air dampers to suit the particular carbonizing time operated. The producer gas inlet to the leading flues requires to be cleaned from producer dust about every month.

The plant is left in control of the shift foreman, whose duties in the chamber house are confined to turning on and off the steam at the required times, seeing that the draws are commenced at the proper time and that full charges are being put in. He also sees that chambers scurfing are finished and put to work in a proper manner.

No intermittent process of carbonization can be considered to be as clean as continuous vertical practice; but the nuisance of dust and steam has been kept to a minimum by carrying-out the quenching under a tower outside the retort house itself. At Ramsgate, the operation of charging and discharging the chambers occupies three to four hours out of the twelve.

Facilities were provided by my Committee for trying out the Roberts process for the production of free-burning smokeless fuel in our intermittent chambers. It will be remembered that the process consists of suitably blending small coking and non-coking coals, which are carbonized in narrow chambers at high temperatures, the carbonizing period being reduced to about two-thirds the normal carbonizing time for high-temperature work. The results obtained were extremely promising, and a free-burning smokeless fuel, comparatively easily ignited, has been obtained in bulk. The work is proceeding, and it is anticipated that within a short time detailed results will be forthcoming.

The author wishes to acknowledge his indebtedness to the Woodall-Duckham Companies, and particularly Mr. F. S. Townend, for putting at his disposal the information obtained from the large number of tests which they have carried out, for which facilities have been gladly provided by my Committee. These tests were closely followed by my own staff.

TABLE A.—*Typical Carbonizing Results in Intermittent Vertical Chambers at Ramsgate.*

| Test Number | Durham A. | Durham B. | Durham C. | S. Yorks. | Kent. | |
|---|---|---|---|---|---|---|
| Analysis of coal, p.ct.— Moisture | 2·8 | 3·05 | 1·75 | 3·33 | 4·2 | |
| Volatile matter (dry basis) | 30·10 | 29·87 | 33·14 | 34·80 | 28·34 | |
| Fixed carbon ,, ,, | 61·41 | 60·47 | 56·79 | 57·38 | 59·70 | |
| Ash ,, ,, | 8·49 | 9·66 | 10·07 | 7·82 | 11·96 | |
| | 100·00 | 100·00 | 100·00 | 100·00 | 100·00 | |
| Carbonizing time, hours | 12 | 15 | 15 | 15 | 15 | 15 |
| Steaming, duration, hours | 2½ | 3 | 3 | 4 | *Nil* | 3 |
| Weight per chamber per charge, tons | 2·22 | 2·225 | 2·27 | 2·246 | 2·25 | 2·25 |
| Total coal carbonized, tons | 257·4 | 288·67 | 116·37 | 267·2 | 67·5 | 67·5 |
| ,, gas made, c.ft. | 3,774,500 | 4,149,900 | 1,986,400 | 4,068,100 | 823,000 | 912,400 |
| Output per chamber per 24 hours, c.ft. | 65,080 | 51,400 | 62,100 | 54,900 | 44,000 | 48,600 |
| ,, ,, ,, ,, ,, therms | 337 | 264 | 388 | 277 | 229 | 239 |
| Make per ton of raw coal, c.ft. | 14,690 | 14,377 | 17,070 | 15,230 | 12,200 | 13,520 |
| Calorific value, B.Th.U. per c.ft. | 518 | 516 | 477 | 505 | 521 | 490 |
| Therms per ton raw coal | 75·97 | 74·13 | 81·41 | 76·86 | 63·56 | 66·24 |
| Inerts in gas (including oxygen), p.ct. | 11·2 | 11·3 | .. | 12·8 | 14·0 | 13·3 |

**SESSION III. Chairman: Mr. G. A. HEBDEN, President of the Coke Oven Managers' Association.**

**Paper G.**

# The Scope of the Bye-Product Coking Industry.

**By C. P. FINN, B.Sc., F.I.C., M.I.Chem.E., and R. RAY, B.Sc., A.I.C., M.I.Chem.E.**

In presenting at this Congress, the first of its kind to be held representing all the methods and processes concerned with the carbonization of coal, these notes dealing with the coking industry of Great Britain, we would respectfully remind you that the coking section is the oldest branch of the industry. The date of the first application of coke appears very obscure, but as charcoal became scarcer and costlier it was to be expected that coke produced from coal by a process similar to that of charcoal burning would be introduced. Thus the coke producer of to-day is the lineal successor to the sylvan dweller who practised the art of charcoal burning. As a substitute for charcoal, it is worthy of note that Dr. Plot (1686) records that coke was used for drying malt, but that it could not be used for the "melting, fineing, and refining of iron." The end of the 18th century found the application of coke to the smelting of iron very general, and its production in closed furnaces as distinct from piles had commenced. We do not propose to trace the history of the industry through the period of development which resulted in the introduction of the externally heated oven recovering tar and gaseous products, from which has evolved the modern bye-product oven.

In addition to the antiquity of the coking industry in Britain, it can claim to treat by carbonization approximately 50 p.ct. of the coal so dealt with.

Prior to 1914, the practice in Great Britain was, speaking generally, to put down at a colliery producing coking coal a plant large enough to carbonize the output of smalls of that pit and that pit only. This practice did not tend to reduce the operating costs which would result from the introduction of labour-saving contrivances made possible on a larger unit.

The working temperatures were lower than those in use in America, but were in accordance with the practice of construction in high silica fireclay. Except in the South Wales area, benzole recovery was practised, and on some plants rectified products were produced. Washed smalls, often ⅜-in. to dust, was the usual raw material, crushed and charged as compressed cakes or by top charging. Dry run of mine crushed coal was used in exceptional cases.

During the war period the existing plants were pressed to the utmost limits, and in many cases they were extended by the addition of a few ovens of similar type and dimensions to those of the original plant. Bye-product developments during this period were confined to the introduction of benzole recovery and rectification plants, and the manufacture of 25 p.ct. ammonia liquor where possible. The few new coke oven plants erected during this period were based on previous experience, and presented no novel features.

Until comparatively recently, with the exception of a few isolated cases, new constructional activities had been at a minimum. At present, however, there are signs of a considerable revival; and we appear to have entered a new cycle.

There has begun a partial remodelling of the original works, with, in some cases, the ultimate object of a larger complete installation to carbonize a greater amount of coal at a lower cost. There are also several instances of entirely new plants on virgin ground, incorporating the latest labour-saving devices, knowledge, and experience derived from the most modern American and Continental practice.

Practically all these new plants are constructed of high-grade silica brick, and are intended to be worked at higher temperatures than was the old practice. This, in conjunction with the facts that the new ovens are of greater capacity, and, though usually narrower, are higher than the average pre-war oven, makes for a greater throughput per oven at a lower operating cost. This greater capacity, which in some of the new projects exceeds a throughput of 1000 tons of coal daily, is one of the outstanding features of this new cycle of constructional activity. Another feature is that the actual site of some of the larger plants is not at any particular colliery or even at a steel works; the deciding factor apparently being the suitability of the site for the central receipt of raw material from different sources and the disposal of large supplies of gas resulting from the daily carbonization of such large quantities of coal in a single unit.

The primary object of the industry was, and is, the production at as low a cost as possible of a suitable quality of solid metallurgical fuel for the iron and steel industry. The idea that a large coke (similar to that produced in the old beehive oven) was necessary to the good working of a blast furnace no longer holds good. A coke tough enough to stand transit, the rough handling of discharging, skip loading, and furnace charging, and to carry "burden," in size not necessarily larger than 4 in., free from excess moisture and of suitable chemical purity, seems to be the desideratum of the furnace operator. That is what we in the coking industry aim at and hope to achieve; and we trust that the blast furnace manager on his part will second our efforts by ensuring that such coke is associated with an equally dry and carefully graded ore and flux.

The character of the coal carbonized influences the quality of the coke. Hence certain districts are in a position to sell a large percentage of their production for cupola work. The manufacture in bye-product ovens of a coke physically and chemically suitable for crucible steel melting in substitution for the best types of beehive coke is a problem which is deservedly receiving some attention.

The mechanical grading of the coke necessarily removes the portions not considered large enough for metallurgical use, and the coke oven sales department has to find a market for this smaller material after further grading into various sizes. The extension of central heating will absorb a quantity of this material, but the smaller grades are, at times, difficult to dispose of except in those circumstances when they can be used for steam raising.

Our Continental neighbours have some very successful types of gas producers using this breeze, certain of them using up to 30 p.ct. of dust with the coarser breeze. From the success of oven coke in the domestic market it seems more than probable that the foothold thus gained may be permanent, in view of the dryness and lower ash content. If coke is to be recognized as an ideal smokeless fuel, however, it will be necessary to produce a special product with an ash content comparable with that of good coal. This is now being manufactured by some firms, and will be produced in increasing quantities in the future.

If coke is to be supplied to the iron and steel industries at a reasonable price, then the owners of coke oven plants must of necessity exploit to the full what have come to be known as the bye-products of coking. Tar, ammonia, and benzole, and, more important still, the resultant unpurified gas, constitute the principal bye-products.

## TAR.

Coke oven tar varies somewhat in composition dependent upon the coals used, the carbonizing temperature, and the ammonia recovery process employed. The specific gravity ranges from 1·1 to 1·2; and its value to the tar distiller and the manufacturer of road tar lies in the fact that it has to a great extent become the substitute for horizontal gas retort tar, the production of which has diminished as a result of the introduction of vertical retort practice. A product of tar distillation which is commanding attention and an ever-increasing value is that creosote fraction testing 1·025 sp.gr. and containing 20 to 25 p.ct. tar acids. This is an exceedingly valuable oil from the point of view of the manufacture of high coefficient disinfectants.

From some coals the yield of liquid products ob-

tained by distillation of the tar is very low, and the tars produced in conjunction with direct ammonia recovery methods show a similar tendency. In the latter case some of the products are recovered in the form of naphthalene and light oils at the coolers dealing with the gas as it leaves the ammonia saturators; fractional condensation having taken place. Though a large quantity of coke oven tar finds its way to the distilling concerns, much of it is treated at the coke oven installations, and in many cases certain creosote fractions are used as " wash oil " in the recovery of benzole, while any spent or thick oil is re-distilled separately or with the tar.

On some of the larger plants the production goes as far as pyridine, crude carbolic, pure naphthalene, anthracene, and disinfectants.

### AMMONIA.

Ammonia is recovered in the coking industries in quantities up to 36 lbs. per ton of coal carbonized (as sulphate). The former high value of ammonia, whether recovered as sulphate or as 15 p.ct. ammonia liquor, was an important factor in contributing to the success of the bye-product coking process. To-day, the synthetic product competes with the bye-product ammonia. As sulphate quality has to be of the highest neutral grade, the cost of manufacture has to be watched very closely. Many chemists have endeavoured to utilize the natural sulphur of the coal in the fixation of the ammonia, but up to now their efforts can hardly be said to have reached the point of scientific and economic success. Success in this direction would be of inestimable value to the coking and other branches of the coal carbonization industry, and would appear to be well worth striving for. The difficulties seem to be almost too great to be overcome by one experimenter or even by a small group, so that it would appear we have here a suitable problem for solution by concerted action on the part of all branches of the coal distillation industry. The production of ammonia on coke ovens by synthetic processes is referred to later.

Ammonia in the form of chloride, as liquor or as purified salt, is also a recoverable product on plants employing the " direct " system of ammonia recovery. The actual amount varies according to the chloride content of the coal.

### BENZOLE.

The recovery of benzole hydrocarbons by absorption in suitable wash oil—creosote (coal tar or blast furnace) or gas oil—is practised on all coke oven plants. In some cases rectification is proceeded with to the pure stage, and in one instance stops only at the manufacture of intermediates such as nitrobenzene and aniline. The bulk of the benzole finds its way on to the motor spirit market. The dyestuff industry absorbs a portion, and apparently finds its requirements cannot be met at times. Dr. E. F. Armstrong points out that it may be necessary to seek to produce benzole by synthetic means, which statement probably indicates that research work is proceeding in that direction.

### GAS.

The unpurified gas leaving the benzole scrubbers is available for many purposes. In the first place a portion may be applied to the heating of the ovens themselves. This is the normal practice in Great Britain, for, though ovens of the compound or combination type have been erected at collieries and steel works, all are working, so far, on coke oven gas. Many of our Continental neighbours, however, are using producer gas, blast furnace gas, or mixtures of these with coke oven gas. The reason is not far to seek, as the gas from the ovens is of such high calorific and monetary value as to be disposed of to better advantage than for the heating of the ovens themselves. The surplus over and above the actual oven heating requirements may be utilized in other directions; and this varies in value according to the situation of the coking installation. In few cases is much actually blown to waste, and then only in exceptional circumstances. The quantities of surplus gas available in the future will probably be somewhat greater, as the new batteries under construction and in contemplation are all of the regenerative type, while, in addition, a greater surplus is claimed than was usual with older ovens of the same class.

The outlets for the surplus gas may be set forth as follows:

(1) Sale to public gas supply undertakings.
(2) Disposal for industrial purposes.
(3) Power generation—gas engines.
(4) Steam generation.
(5) As source of ethylene, hydrogen, and methane.

The use by public undertakings of surplus coke oven gas is the most important of the enumerated outlets. The period 1922 to 1925, in which latter year 4798 millions were taken by statutory concerns, shows an increase of approximately 30 p.ct. Schemes at present in process of development will vastly increase these figures. The usual custom (which is contrary to Continental practice) is to supply the gas in an unpurified condition to the distributing undertaking, which utilizes existing purification plant. The respective responsibilities of buyer and seller are to be discussed in another paper; and we do not propose to enlarge upon this question.

Many of the gas-supplying concerns in the country offer gas to industries at a specially cheap rate, notably Sheffield and Rotherham (both of which exploit coke oven gas) at the price of 3d. per therm. Though 3d. per therm may seem low for purified gas, there are potential buyers to whom this price is prohibitive, but who would find it possible to use unpurified gas at a price of 2d. per therm. In the Sheffield area there are firms who use producer gas in metallurgical operations. The solid fuel (usually washed nuts) for the producer gas plants has often to be carried or transported at a high cost, while in some cases the original producer gas plants are due for replacement. If unpurified coke oven gas could be put into such works at the price mentioned, there is no doubt it would be found acceptable. It is in this connection with such supplies as these that the coke oven industry finds itself hampered by the statutory powers of the gas undertakings. It has, however, no desire to interfere with or compete for what it recognizes as the legitimate business of purified gas supply. To take other cases known to exist, coke oven undertakings are often situated adjacent to works which are possible customers for gas, or, by reason of their exceptional facilities in being close to cheap power and water supplies, find the immediate vicinity suitable for the introduction of a new industry requiring gaseous fuel, Our industry can in such cases meet the wants of such an undertaking, but it may find itself obstructed by the statutory powers of a small local gas undertaking overloaded with capital charges, which is hardly able to keep its head above water while still selling gas at one shilling per therm and upwards. We contend that the statutory powers of a gas undertaking should be of such an elastic nature as to allow the coking industry to place its surplus product to better advantage than often is the case.

Under the industrial uses of gas may be included the manufacture of lampblack, the firing of brick and pottery kilns, glass tanks and lehrs, and, where the ovens are attached to a steel works, its use in reheating furnaces and soaking pits.

The use of coke oven gas in internal combustion engines has not found as great favour as might have been expected in view of the thermal efficiency of that type of prime mover. This may be ascribed to several reasons: (1) The use in the past of unsuitably designed gas engines, often with too high a compression ratio in view of the hydrogen content; (2) the failure to supply a properly cleaned and purified gas; (3) the use of unsuitable hard, and even dirty, cooling water, with consequent overheating; and (4) employment, in many instances, of engineers without sympathetic understanding. That these difficulties can be surmounted, and power produced at a low cost, is shown by the results of an official test carried out not long ago on the Rockingham Coke Works of the Thorncliffe Coal Distillation, Ltd., *vide* Appendix. The waste heat of the exhaust gases is also available for steam generation.

In considering the use of surplus gas for steam generation, it must be pointed out that most coke oven installations have at hand supplies of cheap low-grade fuel either as very fine coal, washery slurry, or coke dust, all of which can be used advantageously on chain grate stokers under water-tube boilers. If no other outlet for gas is available, however, then, perforce, it must be consumed for steam-raising purposes, preferably under boilers of the water-tube type. The large quantities of steam raised may be utilized for the generation of electric power in turbo generator sets; but it is worthy of note that the relative thermal efficiency of the turbine to the gas engine is as 5 is to 7.

The firing of Lancashire boilers by coke oven gas is a most wasteful and uneconomic process. A comparison of the cost of firing such boilers with gas and with coal, this latter at 7s. 6d. per ton, allowing the wages, water, and necessary charges, shows that whereas steam can be produced at a cost of 8d. per 1000 lbs. steam in the case of coal, the cost with gas at 3d. per 1000 c.ft. amounts to 1s. 1·33d. Evaluating

the gas on this basis makes its worth as a fuel something like 1½d. per 1000 c.ft.

Lastly, coke oven gas may be used as the source of such gases as hydrogen, methane, and ethylene where a supply of any one of these may be necessary. On the Continent of Europe and in Japan, synthetic ammonia works have for this reason been located near coke oven installations. This entails a large throughput, such as does not exist in the British coking industry at the moment, as well as the supply of electric power at an exceptionally low price. If this latter difficulty could be overcome, there is the remote possibility of the exploitation of gas piped from a number of coking plants to a central works for the separation and utilization of the constituents.

We have traversed the field of bye-product coking and dealt with the main ramifications of the industry. It may be that the coke oven plants of the next generation will be associated with the production of other products such as liquefied coal, hydrogenation industries, and conversion of solid carbon into compounds required by the ever-expanding needs of mankind; but what the future holds for this important section of the industry concerned with the economic utilization of coal it is very difficult, if not impossible, to prophesy.

## APPENDIX.

### *Power from the Use of Coke Oven Gas in Internal Combustion Engines.*

[Test on 600-B.H.P. Six-Cylinder Four-Cycle "National" Gas Engine and Alternator.]

| | |
|---|---|
| Date of test | May 14, 1924 |
| Duration of test | 5 hours |
| Calorific value of gas at 32° Fahr. and 30 in. of mercury, B.Th.U. per c.ft. (higher value 542) | 491·3 |
| Average kilowatts | 384 |
| Exciter ,, | 4·2 |
| Revolutions per minute | 298 |
| Diameter of cylinders, in. | 18 |
| Stroke of pistons, in. | 18 |
| Mean effective pressures, lbs. per sq. in. average | 64·35 |
| Indicated horse-power, total | 665·3 |
| Brake horse-power total, assuming alternator efficiency 0·93 and exciter efficiency 0·8 | 560 |
| Mechanical efficiency of engine, p.ct. | 84 |
| Efficiency of plant, p.ct. | 77 |
| Gas at 32° Fahr. and 30 in. of mercury, used per indicated horse-power per hour, c.ft. | 14·4 |
| Gas at 32° Fahr. and 30 in. of mercury, used per brake horse-power per hour, c.ft | 16·1 |
| Gas at 32° Fahr. and 30 in. of mercury, used per kilowatt-hour, c.ft. | 25 |
| B.Th.U. per indicated horse-power, per hour | 7,080 |
| ,, ,, brake horse-power, per hour | 7,910 |
| ,, ,, kilowatt-hour | 12,300 |
| Indicated thermal efficiency, p.ct. | 36 |
| Brake thermal efficiency ,, | 32·2 |
| Total thermal efficiency (neglecting power to drive circulating water pump), p.ct. | 27·8 |
| Load factor | 0·96 |
| Circulating water, total lbs. | 349,400 |
| Average inlet temperature of circulating water, ° Fahr. | 92·1 |
| Average temperature of water leaving cylinders, ° Fahr. | 117·3 |
| Average temperature of water leaving exhaust-pipe jacket, ° Fahr. | 121·1 |
| Heat conveyed to circulating water from cylinder walls, B.Th.U. per lb. | 25·2 |
| Heat conveyed to circulating water from exhaust pipe, B.Th.U. per lb. | 3·8 |
| Heat conveyed to circulating water from cylinder walls per c.ft. of gas, N.T.P., B.Th.U. | 183·4 |
| Heat conveyed to circulating water from exhaust pipe per c.ft. of gas at N.T.P., B.Th.U. | 27·7 |

#### HEAT BALANCE.

*Dr.*

To calorific value of 1 c.ft. of gas at N.T.P., 491·3 B.Th.U.

*Cr.*

| | B.Th U. per C.Ft. | P.Ct. |
|---|---|---|
| 1. By heat given up to circulating water from cylinder walls | 183 4 | 37·4 |
| 2. By heat given up to circulating water from exhaust pipe | 27·7 | 5·6 |
| 3. By heat converted to electrical energy | 136 3 | 27·8 |
| 4. By heat comprising mechanical and electrical losses in engine and alternator | 40 5 | 8·2 |
| 5. By heat lost in exhaust gases in radiation, conduction, and otherwise unaccountable for | 103·4 | 21·0 |
| Total | 491·3 | 100·0 |

**Paper H. Session III.**

# Modern Coke Oven Practice.

**By G. J. GREENFIELD and G. H. HARRISON.**

From the numerous points to which we might have drawn attention, we have selected a few which we consider to be of the greatest interest and importance. We propose to deal briefly with the treatment of coal and the characteristics of coke from modern installations, and at greater length with the construction of modern ovens and with heat economy.

### TREATMENT OF COAL.

This subject is dealt with in another paper presented to this conference. We cannot refrain, however, from emphasizing the desirability of blending coals. It must be remembered that as the best seams are being worked out, the present-day coke oven is called upon to treat coals which are inferior to those treated in pre-war days.

The production of a uniformly strong coke is rendered more difficult by the fact that most plants use some impact type of crusher, such as a hammer mill or a Carr disintegrator. Coal is more brittle than the stone which accompanies it, and is therefore broken into much smaller pieces. A typical screen analysis after crushing is:

| | |
|---|---|
| Over ½ in. | 2 p.ct. |
| ½ to ⅛ in. | 18 ,, |
| Under ⅛ in. | 80 ,, |

Yet, of the 2 p.ct. standing on ½ in. sieve, as much as one-half may be stone.

The crushed coal is elevated into a bunker. As it falls from the head of the elevator, the larger pieces of coal tend to roll down the conical pile towards the sides of the bunker, leaving the finer coal nearer the apex in which the larger pieces of stone tend to imbed themselves. In this way segregation occurs both by size and by composition, and the good effects of blending, if practised, are at once partially nullified by the type of crusher. In cases where it is considered desirable to leave the stone in the coal, a solution of this difficulty is to use a roll crusher, so as to reduce the size of the stone particles equally with that of the coal particles. It has been stated that "improper and insufficient mixing has a worse effect on the coke than insufficient crushing." (See B. W. Winship, "Selective Segregation of Coking Coal at the Mine and its Preparation at the Ovens," Eastern States Blast Furnaces and Coke Oven Association, Feb. 12, 1926.)

Stone is removed in two principal ways, washing and dry-cleaning. The washing of coal has been carried on for so many years as to need no description here. Several dry methods of coal-cleaning have become commercially successful, most of them depending upon differences in specific gravity, which enable coal particles to be lifted by an air current of a velocity which will not lift the heavier stone particles. One method (the spiral separator) depends upon the difference of coefficient of friction, but is not applicable to soft bituminous coal, as this class of coal leaves dust on the spiral chute, thereby altering its coefficient of friction. These pneumatic methods will find an increasing place in the preparation of coking coals.

A rough separation of stone has long been practised in America in the "Bradford" breaker. This is an inclined rotating cylinder, with 1 to 1½ in. perforations. It is 15 to 20 ft. long, and 8 to 10 ft. in diameter. The tumbling action breaks the coal, which falls through the perforations, while the tougher stone passes out at the end. The cleaned coal then passes to the blending and crushing plant. Usually the oversize consists almost entirely of stone, with scrap iron, wood, and other extraneous material. In cases where it contains any considerable propor-

tion of coal, it is fed under boilers. This method is worthy of serious consideration by all coke makers.

### THE CHARACTERISTICS OF THE COKE.

With the development of fast coking, the characteristics of the coke have undergone a considerable change. So long as the width of the oven was about 20 in., and the carbonizing time ranged from twenty-six hours for dry coal, up to thirty-five hours for wet coal, the coke produced was of a very dense nature. It would for the most part burn only under forced draught, as, for instance, in the blast furnace. With ovens of 16 in. and 18 in. width, carbonizing in fourteen and sixteen hours respectively, the coke is of a more open texture. This is partly due to the fact that the layers nearest the oven wall are not exposed to high temperatures for such a long time as formerly. Overbaking raises the ignition temperature of coke (S. L. B. Etherton, Coke Oven Managers' Year Book, 1926-27, p. 161). The more rapidly carbonized coke is therefore more easily burned.

It is found possible with modern coke to drive the blast furnace much harder; the production of pig iron being increased very considerably, and the consumption of coke per ton of pig being materially reduced. The coke is also suitable for other purposes for which the old overbaked coke was suitable.

The coke from modern ovens, however, finds another great outlet, namely the domestic market. For this purpose it must be efficiently sized. Coke nuts from an oven 17¾ in. mean width, carbonized in fifteen-and-a-half hours, provide an excellent fuel for ordinary domestic grates, and have even been burnt with absolute satisfaction in the modern type of barless grate. We do not know of a more severe test of the suitability of a fuel for household purposes than the barless grate. This is not merely our personal experience. In a Company such as ours it is possible to compare the popularity of the old and the new types of coke. Large numbers of consumers definitely specify that they are to be supplied from the plant which is making fifteen-and-a-half hour coke, as they find the nuts from it superior, for domestic and similar purposes, to those from the plants carbonizing in twenty-six hours.

### CONSTRUCTION OF MODERN COKE OVENS.

The development of the large oven has been made possible by the regenerative principle. There is no doubt that ovens of 10 ft. to 14 ft. in height could not be heated either evenly or economically if the gas had to be burnt with cold air. Regenerators also make it possible to heat ovens with producer, blast furnace, and other low-grade gases. In these cases the fuel gases themselves pass through part of the regenerators.

Almost without exception, the recently constructed batteries are regenerative, and are built with silica walls. Some builders use silica throughout right down to the bottom of the regenerators. Others use silica except for the few bottom courses of the regenerators, which are of semi-silica. One firm uses silica to the oven sole level only, and builds the regenerators entirely of semi-silica.

One of the main reasons for building walls of silica bricks is that at high temperatures they are of greater mechanical strength than semi-silica bricks. This is of special importance when one takes into consideration the size of modern ovens. A battery is now being built in England with oven chambers of the following dimensions:

| | Ft. | In. |
|---|---|---|
| Length | 44 | 7 |
| Chamber height | 14 | 0 |
| Average width | 1 | 5¾ |

A battery has been built in Germany having ovens 15 ft. high. The walls in these batteries are only 4 in. thick. It is well-known that if ovens of these dimensions were built in anything but silica and worked with temperatures of 1350° to 1400° C. in the flues, the walls would soon soften, buckle and collapse.

One of the reasons why large silica ovens have not been built in greater numbers in England is that coke producers had doubts as to the expansion that would take place during the heating up of such a battery.

Some care is required in the heating up of a modern silica battery. The heating period should be fully six weeks, and preferably eight weeks. Temperature and time charts should be prepared and strictly followed. On a battery known to us, the total rise in temperature at the end of the second week was only 50° C., and at the end of the third week only 110° C. This was done to allow the moisture in the brickwork to be driven off slowly. Local violent fluctuations are destructive, and must be avoided. The temperatures of greatest expansion of silica are between 220° C. and 275° C., and at 575° C. Therefore, only when about 600° C. has been reached can the firing be accelerated with any degree of safety. Above this temperature heating may be pushed forward as fast as desired.

The expansion during heating up is taken care of as follows:

(*a*) Longitudinal expansion of the battery is allowed for by expansion joints at each oven. These are about ⅞ in. wide.

(*b*) Cross or transversal expansion amounts to about 6½ in. in a 40 ft. oven. There are no expansion joints provided in this direction, and the tie rods are slackened off during heating up.

(*c*) Vertical expansion needs no special care, except that as the gas collecting mains are supported on the buckstaves, which do not expand with the brickwork, allowance must be made for the ascension pipes being raised 2¾ to 3 in.

If attention is paid to these points, there is no more trouble in heating up silica walls than other walls.

The ironwork used on modern batteries is worthy of attention. Builders are using not less than 10 in. by 3 in. channels for buckstaves. Massive cast-iron flash plates are used which, in most cases, overlap the ends of the oven walls. Transverse tie rods are about 1¾ in. diameter, and longitudinal tie rods about 3 in. diameter.

Ascension pipes are made as short and of as large a diameter as possible; average dimensions being 8 ft. 6 in. high by 14 in. diameter. The practice of lining them with refractory material is now being introduced. Several forms of ascension pipe valves are being constructed; the pan-sealed type coming into great favour. In every case they are flushed with large volumes of liquor.

Collecting mains are of rugged construction. They are made in flanged sections of about 18 ft. long, and are supported entirely on the oven buckstaves. This takes the strain off the oven brickwork, and prevents the distortion which is often noticed on old batteries. Pitch troubles with these mains are unknown. They are generally constructed on the "dry" principle, and are flushed with large volumes of liquor. Where the battery is large enough to make it desirable, the collecting main is subdivided. On a sixty-oven battery under our notice there are two collecting mains, one for each thirty ovens. Liquor containing 0·5 p.ct. of ammonia is circulated at the rate of 30,000 gallons per hour. The two offtake mains are connected to the centres of the collecting mains, so that the gas has to travel, at the most, only the width of fifteen ovens before entering the offtake main. This favours an even pressure in all the ovens. Collecting main offtakes are fitted with governors which regulate the pressure in the collecting mains within fine limits, so that the battery can be kept free from smoke without overpulling. This is a major factor in preventing pitch deposits. Such governors are absolutely essential for efficient working.

The modern coke ram is of massive construction, weighing about 100 tons, compared with the 40-50 ton rams in use on old ovens. It has a beam about 30 in. deep, weighing up to 15 tons, whose weight is carried, when in the oven, by a sliding shoe instead of rollers. There is often a separate motor for each motion, and the ramside door extractor is generally fitted on this machine.

Plug type doors are universal on modern ovens. With the American type, used in conjunction with cast-iron flash plates which provide a metal door jamb, very little luting is required. In Germany, self-sealing doors, on which asbestos strips are used as the jointing medium, are finding favour. As these strips are expensive to renew, and in some cases only last three to twelve months, we think the self-sealing door is at present inferior to the American luted type, but it will probably be developed and become universal.

Remote quenching is now common, and was first introduced in order to prevent water from coming in contact with the hot silica bricks, and because, with increasing size of oven, it was found impossible to quench evenly a big charge piled up on the bench. It also results in more pleasant working conditions. It is carried out in most cases by discharging the coke through a combined coke guide and door extractor into a coke car. This is taken to a tower, and the coke quenched with water; the quenching taking about 65 seconds. The coke is dropped on

to a wharf, from which it is elevated by a rubber belt to the screening plant. Rubber belts are nearly always used in this system, and are giving every satisfaction.

In another method of quenching, which is being tried in Germany, the hot charge of coke is pushed into a tipping coke box to prevent breakage during discharging. This machine is like a long coke guide, and, after receiving the coke, is turned on to its side and taken to a quenching station in the usual fashion. After quenching, the coke is pushed out over a parallel bar screen by a ram having a horizontal head. This practice prevents coke breakage, in that the drop into a coke car, which is at least 10 or 15 ft., is avoided. We do not advocate this or any other method of "nursing" the coke. The coke on being discharged from the oven has a certain amount of cross-fracturing, and will ultimately break up to some extent. If it is protected from breakage until it gets into the rail wagon, it will subsequently break, either in the wagon or on discharge at its destination, resulting in an unsatisfactory proportion of "breeze." We prefer that it should be handled with a reasonable degree of roughness before it arrives at the screening plant, so that pieces which are to break off will do so, and become part of the nuts and ballast fractions, leaving only coke which is really coke to be sold as such.

No coke oven plant in England is using a dry cooling system, although one has been installed at a gas-works. A few batteries on the Continent are operating such systems, one of which is the Sulzer process. The plant consists of a coke chamber and a firetube boiler. Hot coke is introduced at the top of the chamber and let out at the bottom at about 200° C.; its sensible heat being removed by inert gases which are circulated by means of a fan, over the coke, and through the boiler. In proportion to the amount of coke handled, it is a large and cumbersome plant, and produces a good deal of breeze; but for small installations, especially those depending upon the domestic market, it is of considerable interest. In another dry method, the hot coke, instead of being elevated, is dropped into a large hopper where it is cooled by inert gases and then discharged on to pan conveyors which elevate it to the screens. This reduces the amount of dropping.

Top charging by an electrically driven coal car is now customary, and in most cases in America and on the Continent weighing machines are installed for weighing the charge. In order that the oven tops may be kept clean and tidy, they should be absolutely level. Coal lorries are being fitted with discharging sleeves to prevent spilling during charging.

The width of the oven was at first reduced in order to reduce the coking time and so increase the throughput per oven per day, the weight of the charge being maintained by increasing the height and length. These latter dimensions, however, are now becoming the limiting factors, so that the original advantage has been nullified.

To illustrate this, let us consider a battery, in which the ovens are 15 ft. high and 44 ft. long, to carbonize 1000 tons of dry coal per day, and compare 14 in. width with 18 in.

| — | 18 In. Width | 14 In. Width. |
|---|---|---|
| Charge per oven, tons | 18 | 14 |
| Coking time, hours | 15½ | 11 |
| Oven capacity, tons per 24 hours | 27 9 | 30·5 |
| Number of ovens required | 36 | 33 |
| „ „ charges per 24 hours | 56 | 72 |

Thus only three more ovens are required in the 18 in. battery than in the 14 in. battery, while the narrower oven necessitates a much larger number of operations. There are other things to be taken into account. The narrower oven requires a slightly smaller coal lorry, coke car, and ram, and less ground space, but the slight reduction in capital cost is far outweighed by the greater number of operations.

The size of coke required and the properties of the coal are among the deciding factors. In America and on the Continent, ovens of 12 in. width have been built, and some batteries of 14 in., but the present tendency is to revert to 16 to 18 in. Above 18 in., coking slows down appreciably. Thus a 20-in. oven could not be coked in 18 hours, but would require at least 19 hours.

### NOTES ON THE OPERATION OF A MODERN BATTERY.

During a strike or other slack period, it is not desirable to "beehive" ovens, as is sometimes done. This practice may injure the wall, whether silica or semi-silica, by local overheating, and by bringing it into contact with the ash of the coke, thereby scarring the bricks. In the case of the sixty ovens at Consett which have been in operation for about four years, and have carbonized 1,250,000 tons of coal, forty-five of the ovens were kept empty during the seven months of the last coal strike. The whole battery was kept hot by the gas from the remaining fifteen ovens, which were worked at less than half-speed. A temperature of 950° C. was maintained in the flues of the empty ovens, and 1150° C. in those of the working ovens. When the strike ended, this battery was put into full operation in seven days.

No repairs have been done to the oven chambers; the only signs of wear being on the bottom or sole bricks at the coke side. We are surprised to read the following in the excellent paper on "Ovens as a Gas-Works Carbonizing Plant," by G. M. Gill, in the "GAS JOURNAL" for June 22, 1927, p. 880. "One large firm of horizontal oven builders told the author that they were always prepared to contract over a period of ten years to undertake the entire repairs and renewals of the oven brickwork for 1d. per ton of coal carbonized." Owners would be very foolish to make such a contract. On our plant, we should have paid over £5000 in our four years' operation; actually there have been no repairs at all. We estimate that by the end of our tenth year of operation, these repairs, including labour and materials, will not exceed £100. At the same time, the fact that builders are willing to do this is a proof of the reliability of silica ovens, since any excessive repairs or renewals would quickly swallow up the contract price.

Repairs to oven machinery are not heavy. The ram beam shoe requires renewing at intervals; one will serve for pushing 40,000 charges. The ram beam appears, judging by its present condition, likely to last for twenty years. This is largely due to fast operation. During the whole operation of pushing and withdrawing, the beam is in the oven less than a minute, and does not therefore get very hot.

The cast-steel floor plates of the coke guide have to be replaced about every 17,000 charges. The work of replacement only occupies about one hour.

We have two coke cars, one being a spare. They have cast-steel bottoms, sides, ends, and doors which have needed no repairs up to the present. The top lattice-work is of mild steel, and has had to be renewed twice on each car owing to the corrosive action of the quenching water, with which waste liquor from the ammonia stills is mixed. This lattice-work was intended to prevent coke jumping over the side. We are now leaving it off the car, because we have fitted to the coke guide a coke steadying bar which causes the coke to fall more gently into the car. The coke car is the only oven machine which we have in duplicate.

The coke wharf plates, over which one million tons of coke have passed, are now wearing out, and will be replaced in the spring. The wharf is 90 ft. long and 20 ft. wide

The rubber belt for elevating coke to the screens was replaced when it had carried 550,000 tons of coke. In our estimation the belt now running will carry at least 1,000,000 tons before it is taken out.

The manganese steel discs on the grizzley coke screen are changed when they wear too small; an average life being 140,000 tons per set of discs. Chilled cast-iron discs were originally supplied, but their life was very short.

The longest stoppage we have ever had, which was due to breakdown, has been 3¼ hours. During the whole of the year 1927, we drew an oven every 15½ minutes except that we had:

One delay of three hours.
Three delays between one and two hours each.
Eleven delays between 30 and 60 minutes each.
Nineteen delays between 15 and 30 minutes each.

During the whole year we only missed two ovens. This record is certainly very different from that of some plants of the old type.

### HEAT ECONOMY.

The aim of the designer of modern ovens is to produce an even heat over the entire surface of the oven wall. The speed of coking depends on the temperature applied to the coal; and clearly the greatest efficiency is to be obtained when all parts of the oven wall are submitted to the same steady temperature.

The large modern coke oven presents the problem of providing an absolutely even temperature over an

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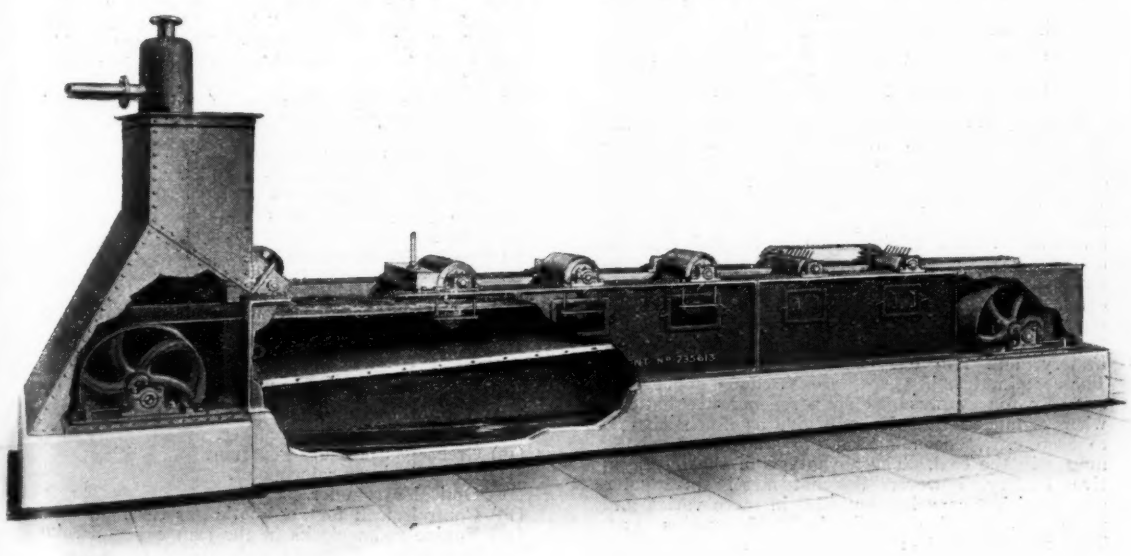

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oven wall as much as 45 ft. in length and 15 ft. in height (675 sq. ft. in area). The ends of the wall suffer radiation losses, and must, therefore, receive extra heat, but the main problem lies in the distribution of heat from bottom to top. This difficulty has been attacked in different ways by the principal construction firms with a considerable degree of success. The methods adopted have been :

(1) Control of the proportion of gas and air in each separate flue by means of individual damper bricks. With the development of knowledge of gas flow and flue design, it has become possible to make a given amount of gas burn as a flame of any desired length over a very wide range. Efforts are made to design the flues so that at full-speed operation the flames are of the right length with a minimum of excess air.

(2) Control of waste heat distribution by subdivision of regenerators.
(3) Tapering the oven so that it is narrower at the top than at the bottom.
(4) Reducing the size of the horizontal flue by :
  (*a*) The " cross-over " flue.
  (*b*) Heating the wall by alternate quarters instead of halves.
(5) Abolishing the horizontal flue altogether by burning in alternate flues (the " hair-pin flue " principle).
(6) Admitting the air by stages at two or more points between the bottom and the top of the flue.
(7) Introducing the gas in steel pipes below the regenerators and leading it up vertical ducts to the flues. This gives more exact control of the quantity of gas fed to each flue than introducing it by a horizontal duct above the regenerators and admitting it to the flues by fireclay nozzles.

Claims are now made for a difference of not more than 20° to 30° C. between the bottom and the top of the oven wall.

The importance of this problem is recognized by all designers. In so far as we fail to solve it, to that degree we suffer from the following disadvantages :

(1) If the charge is left in the oven until the top is finished, heat is wastefully applied in overcoking the bottom.
(2) Either the bottom is overcoked, thereby becoming less efficient for a blast furnace, and resulting in excessive breeze production, or the top is underdone, resulting in uncoked and partly coked coal and in loss of bye-products (volatile matter not being expelled).

Economy has also been effected by improvements in regenerator design. With the progressive improvement of regenerative ovens, claims of as much as 65 p.ct. of surplus gas are made. The actual superiority of the regenerative over the waste-heat battery from the thermal point of view is difficult to estimate. Parker (Coke Oven Managers' Association Year Book, 1926, p. 117) gives theoretical figures for steam raising which show very little difference between waste heat and regenerative ovens. Huessener (" Gas World," Dec. 5, 1914, p. 13) gives 1·04 tons of steam per ton of coal on a waste-heat battery, and 1·19 tons for a regenerative battery. These estimates, however, are based on about 5500 c.ft. per ton surplus gas on a regenerative battery, whereas modern practice will give as much as 6500 to 8000 c.ft., depending on the amount of volatile matter in the coal. The advantage of the regenerative battery, however, lies not merely in greater steam raising capacity, but also in more varied and more remunerative applications of surplus gas. Thus the gas can be :

(*a*) Sold for domestic use.
(*b*) Sold for industrial uses, displacing producer gas.
(*c*) Consumed in internal combustion engines for electric power production.

In mentioning surplus gas, we wish to emphasize that it is more desirable to state the heating efficiency of an installation in terms of B.Th.U. consumed per lb. of natural coal carbonized, than by stating the fuel gas as a percentage of the total gas. The total gas varies considerably, according to the volatile content of the coal, so that the latter figure is sure to be misleading. We consider that the former figure should be reduced to represent the heat consumed per lb. of ash-free and moisture-free coal, but at present there is no agreement as to the allowances to be made for ash and moisture.

In America, and in cases in this country, where it is possible to measure accurately the heat input to the battery, 1000 to 1100 B.Th.U. per lb. of natural coal is considered good practice. In some cases in Germany claims are made for as low a consumption as 750 to 800 B.Th.U. per lb. While we do not wish to deny these claims, we recommend that they be accepted with caution. We have experienced a short period of half throughput on a battery normally consuming about 1100 B.Th.U. per lb., and, while the period was not long enough to arrive at any definite figure, it was sufficient to indicate that at that speed the heat consumption was going to work out at between 800 and 900 B.Th.U. per lb. (Against this, there is a theroretical paper by R. W. Davies (" Gas World," April, 1926), in which it is stated that the heat consumption per lb. *increases* with decreasing throughput. This opinion is not generally accepted). We therefore think it likely that these low Continental claims, even though based on actual large-scale tests, were probably achieved on low throughputs, and might not be maintained at full throughput. We accept the figure of 750 B.Th.U. with reserve, but, in view of improvements which are being made in design, we believe that 900 B.Th.U. may be achieved at full throughput on batteries now being built.

A reduction of heat consumption by 100 B.Th.U. per lb. of coal carbonized would result in a saving of 81,760 million B.Th.U. per annum on a plant carbonizing 1000 tons of coal per day. At 6d. per 1000 c.ft. of 500 B.Th.U. gross per c.ft., this is worth £4088.

Another factor in heat economy which may be mentioned is the increasing use of measuring, recording, and governing instruments. In a congress such as this is it is not necessary to dwell upon the advantages of this policy. It is very remarkable to realize how much progress was made with no scientific instruments, or very few, in the early days of the industry, and it is pleasing to know that a number of coke oven plants are putting in scientific instruments, one by one, while new installations are more or less completely equipped in this respect. This development, however, is still so much in its infancy in this country that it is difficult to obtain any reliable figures for most installations as to the amount of heat required for the coking process. Most plants, with the exception of those erected since about 1923, have no gas meters, and the few that have, generally consider that their meters are unreliable. Meters can now be obtained with a guarantee of accuracy within 2 p.ct.; and in our case this guarantee has been substantiated.

We consider that a battery should be equipped at least with the following instruments.

(1) Total gas volume meter and recorder.
(2) Surplus gas volume meter and recorder.
(3) Fuel gas volume meter and recorder.
(4) Fuel gas pressure recorder.
(5) Fuel gas pressure governor.
(6) Stack draught recorder.
(7) Stack temperature recorder.
(8) Stack draught governor.
  (6*a*) Air pressure recorder where air is supplied by a fan.
  (6*b*) Air volume meter and recorder where air is supplied by a fan.
  (8*a*) Air pressure governor and recorder where air is supplied by a fan.
(9) Green gas pressure recorder.
(10) Green gas pressure governor.
(11) Recording gas calorimeter.
(12) Optical pyrometer.
(13) Control clock for automatic gas reversal.
(14) Engine room clocks in the ram cab and coke loco. cab.

We believe that our plant was the first in this country to be so completely equipped, and we believe that the instruments have paid for themselves many times over.

Efforts have been made to recover in a useful form some of the sensible heat in the hot coke, which amounts to about 400 B.Th.U. per lb. of coke. The best-known of these processes is the Sulzer dry-cooling process. This has yielded 429 lbs. of steam from water at 110° Fahr. to steam at 139 lbs. per sq. in. per 1000 lbs. of coke, which is equivalent to 490 lbs. of steam, from and at 212° Fahr., per 1000 lbs. of coke. (Beebee, " Gas Engineer," Sept., 1927, p. 229.) Some air must enter the system with every charge of hot coke. No information is available as

to the proportion of the heat recovered which is due to combustion of the coke; but as the calculated equivalent evaporation is only about 415 lbs. per 1000 lbs. of coke, combustion must play a part.

In the effort to achieve maximum efficiency, it has been realized that each charge has to be carbonized for exactly the same length of time. Every wall in the battery is naturally treated with the same amount of heat as far as is practically possible except, of course, the end walls; and if this rate of heat input suffices for one charge, it should suffice for any. Thus we have the introduction of the schedule, where a list of times is issued to the men, and ovens are pushed and loaded exactly in accordance with these times. The result of the adoption of this method is that each charge can be given the amount of heat required to carbonize it and no more. Besides resulting in a saving of heat, a schedule ensures that the coke produced is of a regular quality so far as this may be influenced by the conditions in the oven. It also ensures a steady flow to the bye-product plant of gas of very even composition. The value of this point is specially great, in view of the present tendency on the part of the coke oven owners to sell their surplus gas. The adoption of schedule operation cannot bring its full benefit unless every charge is of equal weight. A weighbridge, to weigh every charge in the lorry, should be installed on every plant.

Schedule operation can only be maintained on plants of robust construction, such as are now being erected. On older plants, distortion of oven walls renders the oven of unequal width, so that in the course of two or three years' operation, different ovens in the same battery will require different carbonizing times.

Lastly, there is the question of width of oven, which is dealt with in another part of this paper. In any oven, sufficient heat must be transmitted to the centre of the charge to complete the process of carbonization; and this implies a temperature gradient through the coke. In other words, in order to get the centre hot enough, the sides must be made hotter than is strictly required for carbonizing. Heat has not to be transmitted so far in a narrow oven as in a wide one. This results in a reduction of the heat required, not only for sensible heat in the coke, but also for heat loss by radiation from the structure. By far the major part of this advantage is secured in reducing from 21 in. width to 18 in. The present tendency is to abandon the 14 in. oven and return to 18 in.

### CONCLUSION.

We have attempted to show the present trend in regard to the design and operation of coke ovens. Our remarks on the treatment of coal and the nature of the coke have been limited to the mention of one or two matters to which we attach such importance that we feel they cannot be omitted from such a paper as this.

We have mentioned some of our own experiences on a modern battery, in order to show the practical effect of the methods of construction now being practised.

We have described the factors which influence the design of heating systems, and the principal lines upon which such design is progressing. We hope we have sufficiently emphasized the importance of operation by schedule and of the use of instruments and other devices for securing maximum efficiency.

As there is now a Committee in existence for the express purpose of devising standard tests for the strength and other properties of coke, we have omitted any discussion on these questions.

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**Paper J. Session III.**

# Coke Research in the Iron and Steel Industry.

**By E. C. EVANS.**

The iron and steel industry was developed in Great Britain under cheap fuel conditions, and while there was a gradual rise in the cost of fuel between 1885 to 1913, from an index figure of about 55 in 1885 to 100 in 1913, fuel prices in relation to those existing in Continental iron and steel producing districts were not such as to prove a serious handicap to our manufacturers in the intensive competition with which the industry has been faced since the Continental countries and America became producers on any considerable scale. The very rapid change, however, which took place during the war, which raised index numbers of wholesale coal prices from 100 in 1913 to the figures shown in Table I., found the country unprepared; and in 1923 the National Federation of Iron and Steel Manufacturers formed a Fuel Economy Committee under the chairmanship of Mr. M. Mannaberg, to investigate possibilities of increasing fuel efficiency in British iron and steel practice.

TABLE I.—*B.O.T. Index Numbers of Wholesale Coal Prices.*

1913 Index No. 100. Aver. for 1920, 332·1; 1921, 242·9; 1922, 171·7; 1923, 179·3; 1924, 172·3

| — | 1924. | 1925. | 1926. | 1927. |
|---|---|---|---|---|
| January | 179·7 | 158·5 | 142·0 | .. |
| February | 183·5 | 156·2 | 141·6 | .. |
| March | 189 4 | 152·9 | 139·3 | 147·1 |
| April | 192·3 | 150·6 | 142·1 | 138·8 |
| May | 180·5 | 148·9 | .. | 130·5 |
| June | 170·3 | 143·9 | .. | 123·1 |
| July | 167·6 | 145·6 | .. | 119·8 |
| August | 163·7 | 141·9 | .. | .. |
| September | 163·1 | 139·1 | .. | .. |
| October | 160·4 | 138·2 | .. | .. |
| November | 160·1 | 138·0 | .. | .. |
| December | 164·0 | 140·7 | .. | .. |

Coke cost played such a predominant part in the total cost of iron and steel manufacture, amounting in fact to over 40 p.ct. of the cost of pig iron production, that it was considered desirable that the possibilities of reducing fuel consumption in blast furnace practice should be the first problem for investigation. A preliminary examination showed that coke consumption per ton of pig iron had increased considerably during the period of the war, and that this increase had been most pronounced in districts where coke quality had decreased either owing to deterioration in the quality of the coal used in coke manufacture, or to inefficient methods of preparation. The coke was considerably higher in ash content than it was previous to the war (and in this connection, increase in coke consumption was greatest in those districts served principally by independent coke oven plants).

Theoretical opinion, however, with reference to the desirable physical qualities in coke was at that time in a state of flux. While some blast furnace managers desired a hard coke capable of standing conditions of handling, transport, and abrasion in the blast furnace without serious breakage, another school of practical and theoretical investigators considered that combustibility or reactivity was a property of the greatest importance in securing efficient operation. The theoretical problems involved were complex, and necessitated consideration not only of the effect on blast furnace operations of the physical condition of coke, but also of the chemical reactions taking place between the various elements of the charge—coke, ore, limestone, reducing gases, and so on—under blast furnace conditions at temperatures varying (say) from 250° to about 1550° C.

In order to explore the position, two investigations of a fundamental character were inaugurated by the Fuel Economy Committee in 1924—namely:

(1) Investigation of reactivity of British cokes to carbon dioxide under standard conditions of temperature, and so on.

(2) Investigation of the reactions taking place between blast furnace gas and ore at temperatures corresponding with those in blast furnace operation.

The investigation on coke reactivity was proceeded with by the Fuel Research Division at the request of the Committee, under the direction of Mr. F. S. Sinnatt and Dr. J. G. King; the research being conducted by Dr. J. H. Jones, assisted by Mr. S. L. Smith. The second research, on blast furnace reactions, was undertaken by Prof. W. A. Bone, F.R.S., at the Imperial College of Science and Technology;

Dr. L. Reeve, A.I.C., and Dr. H. L. Saunders, F.I.C., being appointed as Research Chemists.

Preliminary reports of the work done by these observers have been published[1 and 2].

It was thought desirable also that work should be started on the individual cokes produced in the various districts of this country; and through the instrumentality of Prof. R. V. Wheeler, of the University of Sheffield, the Midland Coke Research Committee was formed in February, 1926, consisting of representatives of the Ironmasters' and Coalowners' Associations of the Yorkshire and Derbyshire coalfields (together with some individual firms), who, with the Department of Fuel Technology of Sheffield University, financed the work. The Coke Oven Managers' Association is represented on this and other committees. The work was directed by Profs. C. H. Desch and R. V. Wheeler; and Mr. R. A. Mott, M.Sc., A.I.C., was appointed Technical Officer of this Committee. Results within a short period were so promising in character that on Nov. 9, 1926, a further Committee was formed in the Northern area embracing the coalowners and ironmasters of the North-East and West Coast districts, directed by Profs. H. V. A. Briscoe and Granville Poole, of Armstrong College, Newcastle-on-Tyne; the technical work being under the control of Dr. W. T. K. Braunholtz, M.A., F.I.C.

A further Committee was formed by the Scottish ironmasters and coalowners in May, 1927; the general direction of the work being undertaken by Prof. Thomas Gray, of the Royal Technical College, Glasgow, and the technical work being under the control of Mr. W. J. Skilling, A.R.T.C., A.I.C. The various committees are assisted by a grant in aid by the Department of Scientific and Industrial Research, and representatives of the Fuel Research Division and of the Fuel Economy Committee of the National Federation of Iron and Steel Manufacturers have been appointed on all committees.

Investigations are still proceeding, and as yet no definite conclusions can be drawn; but there appears to be every possibility that the researches in progress, whether of the fundamental character of those on coke reactivity and blast furnace reactions, or of the more specialistic and empirical type by the various district Coke Research Committees, will, in the near future, be capable of definite correlation with results of operating practice, particulars of which are at present being collated by the Fuel Department of the National Federation of Iron and Steel Manufacturers.

### METHODS OF TESTING.

The methods of testing coke samples submitted vary to some extent at different centres; but every attempt is made to secure correlation of results by interchange of samples between the various centres, so that as many methods as possible, for investigation of a given coke, can be used. In general, the following determinations are made[2]:

(1) Analysis of coke tested (determination of moisture, volatile matter, ash, sulphur, and fixed carbon).
(2) Determination of the reactivity of coke to carbon dioxide under standard conditions.
(3) Determination of coke combustibility.
(4) Screening test of coke.
(5) Shatter test of coke.
(6) True abrasion test of coke.
(7) Barrel abrasion test.
(8) True and apparent specific gravities.
(9) Apparent porosity.
(10) Capacity of coke for absorbing moisture.
(11) Combustibility of coke.
(12) Examination of coke structure by Rose's method.
(13) X-ray examination of cokes. Kemp and Thompson's method.

### CORRELATION OF INVESTIGATION WITH OPERATING BLAST FURNACE PRACTICE.

Side by side with the above work, a systematic tabulation of records of blast furnace practice in this and other countries has been undertaken by the Fuel Department of the National F deration of Iron and Steel Manufacturers, with a view to ascertaining the influence of the various factors involved, including coke quality, on the fuel consumption. The problem is a complex one. There are something like 20 factors to be considered; and the permutations and combinations of these would involve an enormous number of variables, so that an alteration in any one of them might be very difficult to trace, owing to other factors having been changed at the same time.

A tentative method of expressing to some extent, in a general mathematical expression, the effect of various factors involved has been evolved by Mr. F. J. Bailey, of the Fuel Department of the National Federation of Iron and Steel Manufacturers, and the writer based upon the method of determining operating furnace efficiency by means of characteristic furnace curves which has been in use for some time in Continental iron and steel practice, and which was developed independently by Mr. H. C. Armstrong in this country[4].

Mr. Armstrong, and other workers on the subject, have shown that in metallurgical furnaces working at a standard temperature, the fuel consumption and the output can be correlated by the general formula:

$$C = R + x\,I.$$

Where C = Total fuel required per hour.
R = Fuel required to maintain furnace at constant temperature when no stock is heated.
$x$ = Fuel required per unit weight of stock per hour.
I = Weight of stock heated per hour.

In blast furnace practice, the work of the observers of the Bureau of Mines has shown that slag and iron temperatures are approximately constant in different furnaces; the averaging running temperature of the iron being 1450° C. and of the slag 1500° C., and the results varying within *plus* or *minus* 100° over a wide range of qualities of iron and slag.

As a preliminary assumption, therefore, it was taken that blast furnaces operate at an approximately constant hearth temperature; and from results of operating practice it was ascertained that the following formula could be applied to conditions of heat production in the hearth of operating blast furnaces.

$$C_1 + C_2 = R + XI + \cdot 28\,S.$$

Where $C_1$ = Carbon burnt per hour (lbs.) per sq. ft. hearth area.
$C_2$ = Equivalent of blast heat in lbs. of carbon per sq. ft. hearth area per hour.
R = Figure for external heat loss from an area near the hearth.
(For furnaces with water cooled boshes, $R = \frac{500}{D}$ generally, where D = hearth diameter.)
I = lbs. iron per sq. ft. hearth per hour.
S = lbs. slag per sq. ft. hearth per hour.

If the factor X were constant, this would imply that in blast furnace, as in metallurgical furnace, practice, an increase in output would necessarily involve a decrease in fuel consumption; but taking results over a period from several furnaces, it was found that this was not necessarily the case, and that the factor X was increased:

(1) According to the quality of the iron as indicated by the proportion of silicon in the pig iron,
(2) Inversely according to the time of the material in the furnace,
(3) Generally by any other factors which would result in an increase of hearth reduction.

In this connection, a study of a number of British furnaces showed that those furnaces using coke of high grade quality, had generally a lower X factor than those of poor quality; but it is uncertain as yet whether other factors—for example, influence of ores used, influence of furnace lines, and so on—have not played a part the extent of which as yet cannot be estimated.

A study of individual operating results, however, definitely shows that, other factors remaining the same, improvement in the blast furnace quality of the coke was associated with a decrease in the X factor, and also generally by an increase in output. While, in general, using the same coke, the theoretical fuel saving that would be effected by increased output of the furnace is counterbalanced by an increased X factor (for hearth reduction) due to the smaller time of contact in the furnace, improvement in coke quality, which would allow a bigger output without greater hearth reduction, becomes a question of first importance to the blast furnace manager; and in this direction investigations now in progress at different research centres are throwing a considerable light on the properties of coke required to effect this.

It is perhaps significant that all records which have been received showing improvement in furnace operation effected by an alteration in coke quality indicate that the furnace offers less resistance to the blast than was the case with the poorer coke formerly used. The relation between pressure and volume of blast is not generally clearly understood; but it is sufficient for practical purposes to consider, as Johnson points out[3], that the same laws can be applied to the blast

furnace as in the case of friction in pipes, so that the following formula would apply.

$$V = \int \frac{P}{R}$$

Where V = Volume of air per unit of time
P = Pressure at the tuyères
R = Resistance of stock to flow of gases

If improvement of physical quality of the coke reduced the resistance to passage of the gas, the pressure remaining constant, the volume of blast would necessarily increase, with a consequent increase in rate of combustion of carbon at the tuyères, increased output, and reduced fuel consumption.

If, on the other hand, increased resistance developed due to the presence, for example, of disintegrated coke in the furnace, then at constant pressure not only would the volume of the blast be decreased, with consequent decrease in output, but at the same time channelling by the gases produced would result in an increase of hearth reduction. This explanation is sufficient to account for most of the phenomena in blast furnace operation consequent upon changes in quality of coke, burdening, and other factors involving alteration in the stock resistance.

### 1. MOISTURE.

As yet, it has not been found that moisture content in coke has, in itself, a deleterious influence on fuel consumption other than the reduction of fixed carbon which it involves; but as high moisture in coke is generally associated with physical weakness, some tests have been made by the Northern Coke Research Committee of the absorption of moisture by cokes of different physical structure. It was found that if the coke was dried to constant weight, completely immersed in water, and the weight noted at regular intervals over a period of 24 hours, the volume of water absorbed by unit weight of coke during the first 2 hours bore no relation either to the mechanical strength as determined by the shatter index, or to the porosity; but after this time, the volume of water absorbed per hour is, on the whole, greater for cokes of low shatter index. High moisture content in coke is not, as a general rule, a question of porosity, but is associated with the degree of fissuring of the coke (the greater the fissuring, the greater the surface area for absorbing water) and with the size of coke pieces—the weaker the coke the greater the proportion of small pieces; and these, owing to the area of surface they offer, absorb more water per unit of mass than the larger pieces.

Generally, high moisture is associated with a weak coke, the use of which in the blast furnace would be accompanied probably by increased resistance to the blast, with consequent decreased output and, further, with channelling of the reducing gas in its passage through the burden, inefficient reduction in the upper portion of the furnace, and, consequently, increased hearth reduction and a higher X factor.

### 2. ASH.

The influence of ash in blast furnace operation was recently dealt with by Chapman and Mott[5]. Figures ascertained and calculated by various observers of the effect of an increase of 1 p.ct. of ash on coke consumption are given by these writers, for the most part approximating to 0·35 cwt. per ton of pig. This figure, however, simply takes into consideration the additional coke required to flux the extra slag that would be made after allowing for the decrease in fixed carbon due to the increase in ash, and agrees very closely with that calculated under similar conditions, from the formula already given, by multiplying slag produced by the factor 0·28 and allowing for the lower fixed carbon in the coke. Such a calculation, however, assumes that every other factor remained constant, which is not generally the case.

Thus C. S. Gill[5] communicated results of two large-scale tests, using low ash coke made by the Consett Iron and Steel Company, which showed that a saving of coke per ton of pig iron occurred in one test averaging 0·42 cwt. and in the other 0·47 cwt. per 1 p.ct. reduction in ash, with accompanying increases in output of 6·4 p.ct. and 6·7 p.ct., respectively, per 1 p.ct. of ash.

The theoretical saving due to reduced slag volume and increased carbon in the coke was, in the case of these tests, supplanted by the saving of fuel resulting from the increased rate of driving of the furnace, with consequent reduced carbon requirements for radiation and other external cooling losses per unit of iron produced. Again, results obtained by P. Derclaye, quoted by Chapman and Mott, showed a saving considerably greater than 0·35 cwt. of coke per ton of pig, per 1 p.ct. of ash. Derclaye's tests extended over four years; and the results available show that, using coke of 10·6 p.ct. ash instead of coke with 16 p.ct.—

(1) The output of the furnace was increased by over 24 p.ct.
(2) Blast temperature was increased from 690° to 882° C.
(3) The blast pressure was reduced from 21 cm. of mercury to 16·5 (probably indicative of a lower X factor).
(4) The silicon in the pig iron was reduced.

The saving due to these factors alone would account for a very considerable proportion of the reduced coke consumption effected. Generally, therefore, the total effect of reduced ash in coke can, in practice, only be ascertained from a knowledge of all the factors involved. If, in addition to the lower slag volume and increased carbon in the coke, the physical quality is also improved, with resulting reduced channelling in the furnace (lower X factor), increased output, lower blast pressure, and possibly reduced silicon content in the pig iron (where this is desirable), the effect of ash removal might easily far exceed that which could be calculated from a knowledge only of the reduced slag volume resulting from its use.

It is also desirable that much more knowledge should be available than is at present the case of the constituents of coke ash. Very little work has been done on this subject; the investigations that have been made having been limited chiefly to the influence of certain inorganic constituents in the coke upon properties such as reactivity, density, and porosity[6].

The recent valuable work of W. A. Bone, L. Reeve, and H. L. Saunders[3] raises some interesting questions in connection with results obtained in practical operation with cokes containing certain inorganic constituents.

It has been shown by several observers that the reactivity of coke to carbon dioxide under standard conditions is increased by the addition of iron oxide[4]; but in the discussion on a paper read by H. Bahr on this subject[7], it was stated by P. Ott that large-scale tests at the Deutscher Kaiser Works had shown that a coke containing from 6 to 7 p.ct. of flue dust, rich in iron oxide, had resulted in a decreased production, increased coke consumption, and increased difficulties in furnace operation.

The question arises whether such a result could be explained on the assumption that carbon deposition in the ferruginous coke occurred within the limits of temperature ascertained by Prof. Bone and his collaborators, resulting possibly in a partial disintegration of the coke, an increased resistance to the blast, and a higher hearth reduction with a resulting increase in the X factor. That such deposition is possible appears to be indicated by some determinations of reactivity to carbon dioxide made by the Fuel Research Division on a sample of coke which had been maintained for a period of over two months in a battery of coke ovens, which were kept red hot by gas from another battery, and subsequently allowed to cool slowly. The proximate analysis of the sample was as follows:

| | |
|---|---|
| Moisture | 0·21 |
| Volatile matter (less moisture) | 0·24 |
| Fixed carbon | 91·08 |
| Ash | 8·47 |

It was found that this coke behaved like other cokes at the outset, and that on continued passage of carbon dioxide a drop in reactivity occurred. On allowing the coke to cool overnight, however, reactivation took place, the reactivity rising considerably, then gradually falling in accordance with normal practice.

On treating the coke with hydrochloric acid for three days, after which time 0·29 p.ct. iron had been removed, the sample showed no tendency to reactivate.

This result could be explained on the assumption that carbon deposition had occurred in the coke due to the presence of reduced iron during the period of cooling in an atmosphere containing carbon monoxide; the deposited carbon with its large area of surface being particularly reactive to carbon dioxide.

Further investigation, however, is necessary before any definite conclusions can be drawn; but these results, and some others that are available, indicate the desirability of a systematic investigation of the influence of coke ash constituents on coke property in relation to blast furnace requirements.

### 3. DISTRIBUTION OF COKE ASH—X-RAY PHOTOGRAPHS.

Distribution of coke ash may be of importance. With good coking coals fine grinding improves coke quality with resulting—

(*a*) Increased production of pig iron in the blast furnace;
(*b*) Lower coke consumption;
(*c*) Reduced resistance to blast.

These results may be connected with the method of distribution of the inorganic material in the coke; and a method of X-ray examination of coke developed by C. N. Kemp and J. L. Thompson[8] is being used by the Northern Coke Research Committee in investigations of ash distribution.

### 4. PHYSICAL TESTING OF COKE.

Several methods have been suggested of testing physical quality of coke. In Germany, the Ironmasters' Association have adopted the "tumbler" test as the official method of determining the physical strength of coke; but in view of the objections that have been raised to this test, chiefly by the American observers, in that it gives results which are due to an uncertain combination of resistance to shatter and abrasion, the Coke Research Committees are provisionally using the shatter test of the American Society of Testing Materials as a standard.

In a recent discussion by the Northern Section of the Coke Oven Managers' Association, several speakers emphasized the desirability of caution in drawing too definite conclusions from the result of this test[9]. Thus A. Middleton quoted a case where better results were obtained in blast furnace operation with a coke of 73 to 77 shatter index than with a coke of 83 to 88. It may therefore be of some service to outline some of the results that have been obtained by the various Committees with this method of testing. It has been shown by the Northern Coke Research Committee that if a coke which had already been subjected to one shatter test (4 drops) is screened, and an average sample of the coke remaining above a 2-in. screen is subjected to another shatter test, the new index is higher than the original one. If, therefore, a coke consignment is sampled at the blast furnace after transport, the shatter index of lumps above 2 in. will probably be greater than the results that would be obtained at the coke ovens—due, of course, to breaking-down under conditions of transport of the weaker portions of the coke.

Further, in the case of cokes made in narrow coke ovens, it is doubtful, as yet, whether the shatter index expressed as percentage of coke remaining above 2 in. screen allows of any direct comparison being made with cokes from a wide oven. In this connection, Table II. of results obtained by the Sheffield Coke Research Committee shows that Kent coke made in a narrow oven, though having a texture and appearance of coke generally associated with good Durham cokes, gave a very much lower shatter index than would be expected.

TABLE II.— *Order of Cokes Using 2-in. and 1½ in. Screens after Shatter Testing.*

| Percentage of Cokes remaining | | | | Difference in Position. | Origin of Coke.* |
|---|---|---|---|---|---|
| On 2-in. Screen. | | On 1½-in. Screen. | | | |
| No. of Coke. | — | No. of Coke. | — | | |
| 1 | 93·9 | 1 | 97·2 | 0 | S. Wales |
| 10 | 89·2 | 14 | 96·5 | + 2 | S. Wales |
| 11 | 88·1 | 10 | 95·7 | − 1 | Westphalia |
| 14 | 87·5 | 11 | 95·0 | − 1 | Westphalia |
| 9 | 84·8 | 6 | 90·9 | + 1 | Durham |
| 6 | 79·7 | 8 B | 90·2 | + 1 | S. Wales anthracite blend |
| 8 B | 78·4 | 9 | 88·7 | − 2 | S. Yorks. anthracite blend |
| 23 A | 74·8 | 23 A | 88·3 | 0 | Durham |
| 17 A | 74·8 | 2 | 87·9 | + 1 | Durham |
| 2 | 73·2 | 17 A | 87·8 | − 1 | S. Yorkshire |
| 8 A | 72·4 | 24 | 85·6 | +13 | Kent |
| 3 | 71·3 | 20 A | 84·6 | + 2 | Cumberland |
| 13 | 71·0 | | | | |
| 18 E | 69·1 | 3 | 84·0 | − 1 | S. Yorkshire |
| | | 13 | 83·0 | | S. Yorkshire |
| 20 A | 68·7 | 5 | 82·8 | + 1 | Durham |
| 5 | 65·0 | 8 A | 82·3 | − 4 | S. Wales anthracite blend |
| 4 | 62·1 | 18 E | 81·6 | − 3 | S. Yorkshire |
| 19 A | 61·8 | 19 A | 81·6 | 0 | S. Yorkshire |
| 16 | 61·4 | 18 C | 80·9 | − 3 | S. Yorkshire |
| 20 B | 60·7 | 19 B | 80·6 | + 3 | S. Yorkshire |
| 18 A | 59·0 | 16 | 80·5 | − 2 | Lancashire |
| 18 C | 57·1 | 19 B | 79·7 | + 2 | S. Yorkshire |
| 18 B | 56·6 | 19 C | 78·4 | + 5 | S. Yorkshire |
| 19 B | 56·3 | 18 A | 77·9 | − 3 | S. Yorkshire |
| 24 | 56·1 | 20 B | 77·8 | − 5 | Cumberland |
| 17 B | 56·2 | 4 | 77·7 | − 9 | S. Yorkshire |
| 7 | 55·8 | 17 B | 75·1 | − 1 | S. Yorkshire |
| 19 C | 53·6 | 7 | 74·8 | − 1 | S. Yorkshire |
| 21 A | 52·4 | 21 A | 73·9 | 0 | Cumberland |
| 21 B | 46·6 | 21 B | 72·6 | 0 | Cumberland |
| 15 | 45·8 | 23 B | 67·1 | + 1 | S. Yorkshire |
| 23 B | 41·9 | 22 D | 64·3 | + 1 | Derbyshire |
| 22 D | 36·2 | 15 | 62·3 | − 2 | Derbyshire |

* For series on 1½-in. screen.

If percentages, however, remaining above a 1½ in. screen instead of a 2 in. screen are taken as representing the shatter index, the results of coke made from Kent coal compare favourably with those from Durham coals, and appear to correspond more closely with the relative position that would be expected from the visual examination of the coke. In the case of cokes made in narrow ovens, it may therefore be found desirable to modify the shatter test in order to bring results into line with those of blast furnace experience. Further, in the case of cokes which are of a somewhat similar order of value as shown by the shatter test (as in the case quoted by Mr. Middleton) it is highly desirable that all other factors—ash content, sulphur content, porosity, and so on—should be examined before definite conclusions are drawn as to the value of the coke for blast furnace purposes.

Some extremely interesting preliminary work has been done at the Fuel Research Station by Dr. J. H. Jones and his collaborators on four Durham cokes of a somewhat similar shatter index but differing considerably in reactivity, which appears to indicate that some of the cokes were much more homogeneous than others. It is perhaps premature to quote these results, as they have not been definitely correlated with the other properties of the cokes examined; but they appear to indicate that in the case of cokes made from somewhat similar types of coal, methods of ascertaining the physical quality additional to the shatter test may be desirable.

Generally speaking, results of shatter tests of a large number of cokes from different districts appear to agree generally with those that would be expected from a knowledge of the practical behaviour of those cokes in the blast furnace.

A very interesting point that has been ascertained is that some correlation appears to exist between the shatter test of coke and the screen test of the coke as received, particularly after a long railway haul, so that the blast furnace managers' method of judging the quality of coke from the proportion of larger sized material shown when the side of a coke wagon is taken down appears to be justified. (This applies only to coke made in ovens of similar width. Coke made in narrow ovens may consist of smaller pieces than is customary with coke from wide ovens, but it may be quite as good and even better for blast furnace purposes.)

Essentially, what the blast furnace manager requires is a test which would allow him to determine what effect the coke has upon the efficiency of reduction in the shaft of the furnace (indicated by the X factor). The shatter test is extremely useful in this direction, as it gives him an idea of the amount of breeze that would be produced from a given coke under conditions of handling, transport, and charging into the blast furnace, and which, by causing channelling, reduces the efficiency of reduction in the shaft of the furnace and increases, therefore, the heat consumption in the hearth. Other tests, however, of apparent porosity, reactivity, and so on, may be desirable; and the possibility of the application of these to blast furnace practice is at present under consideration.

### 5. PHOTOGRAPHS OF COKE SECTIONS.

Photographs of sections of coke embedded in plaster of paris and polished (Rose's method) are useful adjuncts to the shatter test, as the degree of fissuring of the coke as shown by these can be correlated with the shatter indices.

### 6. ABRADABILITY OF COKE.

Considerable work has been done by the investigators of the Midland Coke Research Committee on the resistance of coke to abrasion[3], but no correlation appears to exist between the results obtained and the value of the cokes tested in blast furnace practice. This, however, does not apply to "tumbler" tests on coke, which are certainly capable of some degree of correlation with operating results. This test, however, is a measure not only of resistance to abrasion, but also of resistance to shatter.

### 7. REACTIVITY.

It is doubtful whether the reactivity of a coke to carbon dioxide, under standard conditions, is a measure of its combustibility in air or oxygen, particularly under blast furnace conditions. R. T. Haslam[10] suggests that the reaction rate between oxygen and carbon is a function of the rate of diffusion of oxygen through the gas film surrounding the carbon, whereas the reactivity to carbon dioxide is not governed by this factor, and is determined by the nature and extent of carbon surface. It is therefore

necessary, and in fact desirable, from a blast furnace standpoint, to consider the two properties separately.

Considerable discussion has taken place as to the value of reactivity in blast furnace operation. One school of writers contends that a reactive coke results in a high fuel consumption owing to the increased " solution " which takes place in the carbon dioxide present in the stream of reducing gas in the upper portion of the furnace, with consequent loss of carbon to the tuyères. Another school suggests that reactivity is desirable—

(1) Owing to increased rate of combustion at the tuyères, with consequent increased rate of driving of the furnace and lower fuel consumption; and

(2) Increased direct reduction in the furnace, and consequent reduced requirements in chemical carbon for the reduction of the ore.

The problem is a complex one; and it is not possible as yet to analyze the position completely, as so many factors are involved. However, a study of a large number of operating blast furnace results does not suggest that a relation exists between the reactivity of a coke *per se* (*not taking into account other physical properties which may be concomitant with those affecting reactivity*) and the fuel consumption in the furnace.

At the outset, while solution of coke in carbon-dioxide probably takes place to a varying extent with different cokes—and this in fact is shown by experience in other industries—a study of operating results of between 150 and 200 blast furnaces indicates that the total amount of carbon used other than at the tuyères appears to be remarkably constant. (This has not been definitely proved, as the determination of carbon used other than at the tuyères is based upon the analysis of the blast furnace gas; and few gas analyses can be accepted as being absolutely indicative of the true average composition over the period to which the results refer.)

The calculated amount of carbon used other than at the tuyères in different furnaces varies between 200 lbs. and 550 lbs.; but the majority of furnaces examined give a figure of approximately 350 lbs., no relation having yet been obtained between the figure for any given furnace and the reactivity or physical character of the coke used, the rate of driving, or other factors which may be expected to influence the result.

Carbon used other than at the tuyères includes:

(1) Carbon in pig iron, amounting to approximately 90 lbs. per ton of pig iron.

(2) Carbon used for direct reduction of the metalloids, silicon, phosphorus, and manganese in the hearth, which amount varies from (say) 15 lbs. to 75 lbs. according to the proportion of these constituents in the pig iron produced.

(3) The carbon lost in the flue dust, which again varies considerably (say) from 10 lbs. or less up to 40 lbs.

(4) Carbon lost by reaction with water vapour in the blast, varying according to the humidity of the air.

(5) Carbon used in the reaction with carbon dioxide.

It seems surprising that with all these variables there should be an apparently constant consumption of carbon other than at the tuyères; but as Johnson points out, " the chemistry of the blast furnace is not a chemistry of definite atomic proportions. It is a chemistry of infinitely varying balances among conflicting tendencies[11]." Conditions are dynamic rather than static; and in customary operation any factor which tends to an increase in one or other of the losses in carbon referred to above, appears to be balanced by another which reduces them.

This suggestion needs to be reconciled with the variation in the X factor (hearth reduction) already referred to; but this factor denotes carbon used for meeting not chemical, but thermal, requirements in the zone near the hearth. If, for example, a simple reaction be taken as a case in point—

$$FeO + C \rightarrow CO + Fe$$

(the equation is purposely expressed in this way, but in practice would probably necessitate the production first of carbon dioxide, and subsequent reduction of solid carbon, which ultimately would yield the same result) the carbon for the chemical requirements roughly corresponds to 0·215 lb. per lb. of iron. The carbon to meet the thermal requirements of the reaction on the assumption that carbon is burnt to carbon monoxide is of the same order, and amounts to 0·27 lb.; but in practice much more than this amount would have to be burnt, owing probably to the losses in sensible heat of the gases leaving the high-temperature zone in which hearth reduction takes place.

An approximately constant figure for carbon used other than at the tuyères can, therefore, after allowing for the complex nature of the conflicting reactivities, still be reconciled with a varying X factor.

If the carbon used other than at the tuyères is accepted as being constant, it is difficult to see how reactivity *per se* can affect the fuel consumption. On the other hand, the Fuel Research Division's work[1] shows that there appears to be some connection between the shatter tests of coke as customarily manufactured and their reactivity; resistance to shatter increasing with decreasing reactivity, and *vice versa*. If, as preliminary results obtained by these observers seem to indicate, the properties which tend to increase reactivity in customary cokes are also those which increase liability to shatter, it is possible to correlate fuel consumption with reactivity, but only so far as this indicates weakness in the coke, and not increased reaction with the gases involved. In other words, in customary practice, a coke reactive to carbon dioxide is generally a soft coke, effect of which ultimately would be to increase hearth reduction and result in a high fuel consumption per ton of pig iron.

### 8. COMBUSTIBILITY.

Combustibility of a coke has been defined by Foxwell and Wheeler as that property " which determines the rate of reaction with pure oxygen or with air at a given temperature[12]."

It is well-known that, with certain cokes, faster driving of the furnace is obtained than with others; and at first sight it may seem that this could be capable of correlation with the combustibility of the coke used. It is difficult to determine the combustibility of coke at blast furnace temperature. The Sheffield investigators have made use of combustion tests in an experimental furnace of 1 sq. ft. grate area, in which rate of coke feed and air supply can be measured. Graded cokes are burnt in a bed 12 in. deep with varied rate of air supply, and analyses made of gas samples taken at 1½ in. intervals above the grate; the rates of reaction of different cokes with oxygen and carbon dioxide being determined by calculation from these[3]. The maximum temperatures obtained in the bed are in the neighbourhood of 1700° to 1800°; average temperatures being 1500° to 1650°. The investigators of the Northern Coke Research Committee have devised a most interesting combustibility test by determining temperatures and gas analyses resulting from the combustion of coke 5 to 10 mesh size in a silica tube about 2 in. diameter; temperature determinations being made at different points, the CO : $CO_2$ ratio of the resulting gas being ascertained. Maximum temperatures with this apparatus are of the order of 1200° to 1300°.

These methods of investigation allow of the reactivity of the coke to carbon dioxide and combustibility in air being determined; and there seems to be a tendency for increasing combustibility to be accompanied by a decreasing shatter index. It is, however, extremely difficult to reconcile the property of combustibility of a coke *per se* with blast furnace fuel economy. If, at the outset, one accepts the tentative conclusion that there is a constant quantity of carbon gasified above the tuyères, then with furnaces operating with low fuel consumption the amount of air required to burn each pound of coke charged into the furnace will be lower than with furnaces of high fuel consumption, so that a constant volume of air will burn in a given time a greater weight of coke charged into the furnace than in less economical furnaces. In other words, as Howland points out[13], " low coke consumption goes hand-in-hand with low wind."

This result, however, is not a function of the combustibility of a coke, but is due to a combination of entirely different factors—for example, high iron content in the ore, low slag volume, high blast temperature, correct furnace lines, good physical properties in the coke used, correct distribution of burden, and so on. The reasons for high rates of driving in blast furnace practice must probably be looked for in directions other than that of coke combustibility.

In this connection there are, in blast furnace operation, two methods of blowing—namely:

(1) Constant pressure.

(2) Constant volume.

With the first method, the blast furnace manager

attempts to maintain as constant a pressure at the blowing engines as possible. If the resistance to the blast increases, assuming constant engine speed (the volume of air still remaining roughly constant), the pressure increases. In order to reduce the pressure to the original figure, the volume of air must be reduced; and in order to do this, the engine speed is lowered. In constant pressure blowing, therefore, the rate of combustion of coke at the tuyères is essentially a function of the resistance offered to the blast, which again depends not on combustibility, but on factors already enumerated—the greater the resistance, the lower the volume of air and the lower the rate of driving of the furnace.

In constant-volume blowing, on the other hand, every effort is made to maintain the same volume of air per minute, irrespective of furnace conditions, so that the amount of carbon burnt at the tuyères is constant. If the pressure of the furnace increases, steps are taken by the blast furnace manager to reduce this. These consist generally of reducing the burden, thus increasing the proportion of coke used; combustibility in this case again playing apparently no part in the fuel consumption, but the ratio of coke to pig iron being dependent on other factors.

From a thermal point of view, rate of driving can to some extent be correlated with the X factor. If this is too high, indicative of a high proportion of hearth reduction, the hearth heat requirements of the furnace are increased, a greater proportion of coke must be used per unit of pig iron, and (though the coke consumption per unit of hearth area might remain constant) the consumption per ton of pig iron is increased. Alternatively, if the X factor can be reduced—for example, by better distribution of the gases and ore in the upper portion of the furnace—the burden can be increased; and though the coke consumption per sq. ft. of hearth area might remain constant, the ratio of coke to pig iron is reduced.

A new conception of combustibility in connection with blast furnace practice has been given by Messrs. Perrott and Kinney[14] in the definition: "Combustibility of coke from the standpoint of its use in a blast furnace is inversely proportional to the mean rate of gasification per unit volume of the combustion zone, assuming that other factors remain constant."

In a recent admirable paper on the subject[15], T. L. Joseph suggests that if combustibility refers to those properties which determine the space required for combustion at the tuyères of a blast furnace, the conception might be useful in interpreting blast furnace results. If the zone of combustion in front of the tuyères is smaller, the position of maximum $CO_2$ would be nearer the walls; and faster movement of the stock at the periphery would result. Changes might therefore occur in the extent of preparation of the materials in the shaft, with consequent alteration in hearth conditions (change in X factor). The suggestion that a reduction in volume of the zone of combustion with increasing combustibility of the coke is in accordance with the views expressed by Korevaar[16]; but it is desirable to define clearly the term "combustion zone." If the volume of the combustion zone per unit weight of coke is taken to mean the volume in which the percentage of carbon monoxide is at a maximum, then, if this volume is reduced, the mean temperature of the zone should be higher with a more combustible coke than with a less combustible one, owing to liberation of the same heat in a smaller volume. On the other hand, the investigators of both the Northern and the Midland Research Committees have shown that the temperature in the fuel bed of cokes with low reactivity is considerably higher than with cokes of high reactivity—a result in agreement with the generally known fact that beehive coke gives a higher local temperature in a cupola than a softer, more reactive bye-product coke.

The results, however, of practical observation can be reconciled with the theoretical conceptions involved, by assuming that the endothermic reaction $CO_2 + C \rightleftharpoons 2CO$ commences sooner with a more combustible coke, tending to reduce the maximum temperature attainable, but still allowing of the mean temperature in the smaller combustion zone being greater than the mean temperature in the larger zone with the less reactive coke.

Essentially, the views resulting from the work of the American Bureau of Mines are expressed by Joseph as follows: "Increased rates of driving often observed in practice are believed to be due in a large measure to some condition which changes the extent of preparation of materials in the shaft rather than to changes in the coke . . . streamlines of stock descent, resulting from localized combustion at the tuyères, will produce faster settling of the stock in some parts of the furnace, thus shortening the period for reduction of the ore."

The conceptions arrived at, therefore, by these observers correspond to a great extent to those developed by the writer and his collaborators. Generally, it can be stated that, while a number of results of operating blast furnace practice have been received which, at first sight, seem to indicate that improvement in operation has been effected by the use of a more combustible coke, sufficient details have not been given of other factors involved, such as shatter tests of coke used before and after change in blast furnace operation, character of burden, furnace lines, and so on, which would allow of a definite comparison, by the method suggested above, of the working of the furnace before and after the change in coke quality was effected.

### 9. POROSITY.

Sufficient data have not yet accumulated to allow of any definite connection being made between porosity of coke and blast furnace operation. The work that has been initiated by the American Bureau of Mines in connection with the relative resistance which beds of irregular solids offer to the flow of gases is in this connection of very considerable importance, and, taken in conjunction with the fundamental work of Prof. Bone and his collaborators, on the changes which occur in the solid materials taking part in blast furnace reactions, is likely to be of assistance in the correlation of observations made in practical blast furnace operation with the work that is being done by the Coke Research Committees in this country.

### CONCLUSION.

In dealing with the general question of the influence of coke in blast furnace operation, and particularly in devising methods of examination of coke quality which will be of service to blast furnace and coke oven managers, it is necessary to have a clear conception of the physical and chemical reactions involved; and if any comparison of the value of cokes in blast furnace operation is to be made, the whole of the factors involved will have to be determined.

The method of examination of operating practice outlined in these notes will, it is hoped, be of some service in this connection. It links up the hearth and shaft of the blast furnace, and indicates the desirability of examination of coke properties not only from the point of view of maximum efficiency under hearth conditions, but also in relation to the chemical and physical phenomena under the lower temperature conditions existing in the shaft.

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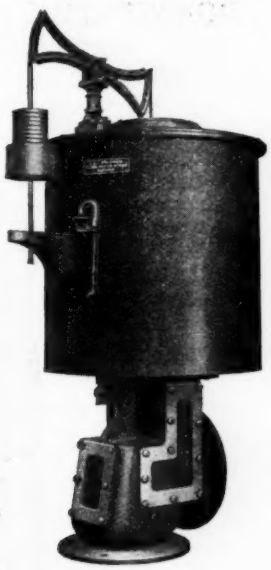

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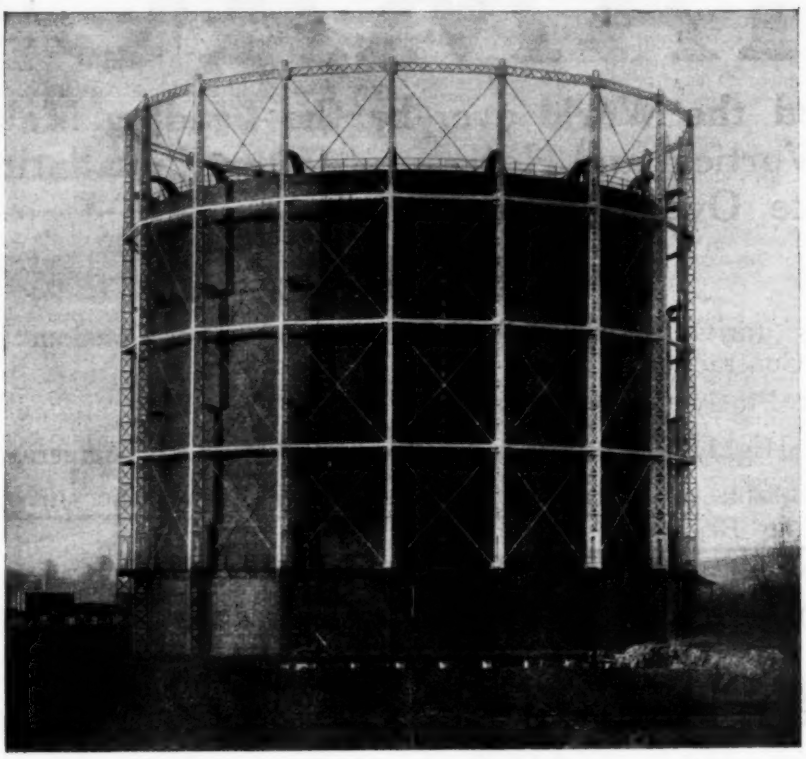

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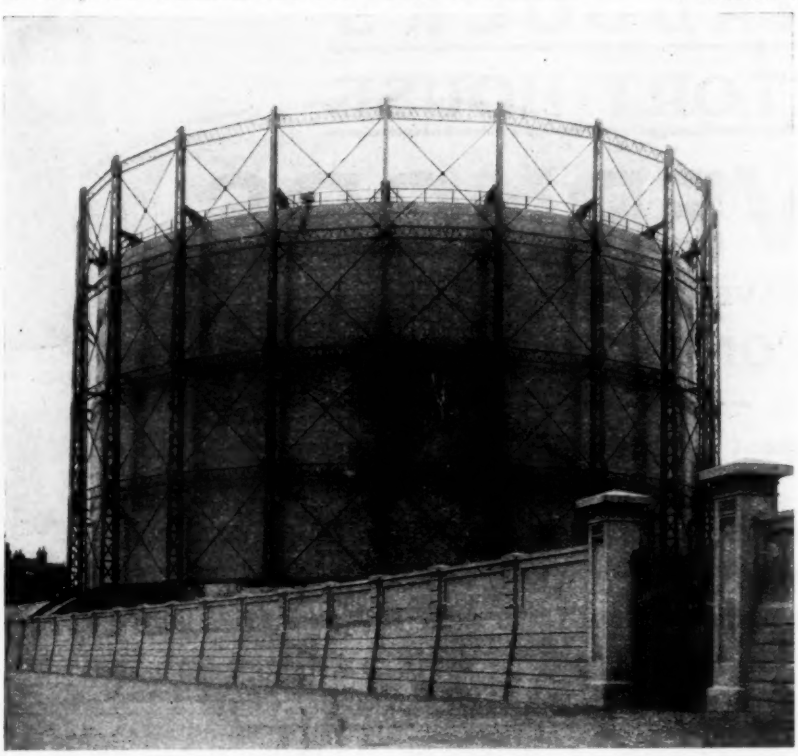

# CAMBRIDGE

*J. W. AUCHTERLONIE, Esq., Engineer.*

**SESSION IV. Chairman : Mr. J. TERRACE, Vice-President of the Institution of Gas Engineers.**

**Paper K.**

# Experiments on the Production of Blue and Carburetted Water Gas in Continuous Vertical Retorts.

**By T. F. E. RHEAD, M.Sc., F.I.C.**

## INTRODUCTION.

In September, 1925, the writer was attracted by the suggestion of the Woodall-Duckham Company* of investigating:

1. The possibilities of blue water gas production from graded coke and steam in vertical retorts; and
2. the cracking of light tars in vertical retorts to produce enriching gas.

Early in January, 1925, he had experienced a difficulty with certain rich coals† of producing a gas as low in C.V. as 475 B.Th.U. in continuous vertical retorts without resorting to excessive steaming or reducing throughput.

If the above suggestion for blue water gas production worked satisfactorily, the writer concurred with the view that it might be used for diluting the gas from other retorts carbonizing certain rich coals with about 5 p.ct. of steam. By this means it might be easier to (1) maintain a uniform quality gas, (2) reduce trouble in the retort house occasioned by some coals which give cokes of a consolidated nature unfavourable for steam cracking, and (3) reduce the dilution of liquor caused by excessive uncracked steam.

The problem of producing useful gaseous therms from the light paraffinic tars of vertical carbonizing was in course of being investigated in our laboratories, and the above suggestion seemed well worth trying as one method of accomplishing the object in view.

It was, of course, appreciated that even when all other factors were favourable, the volume of blue water gas made per hour would be strictly limited by the slow rate of conduction of heat through the retort walls. The maximum output theoretically possible for the ground space and capital involved would be very much smaller than that from the orthodox water gas machine. It would, however, still further improve the flexibility of the continuous vertical system, and under certain exigencies of coal supply and retort conditions might prove very useful.

Furthermore, the preliminary experiments in September, 1925, suggested trying the process for scurfing retorts, thereby possibly saving scurfing time by making useful therms and reducing the wear and tear on refractories occasioned by opening-up retorts for scurfing. The limited time that could be allowed for the tests did not admit of the accumulation of as much data as could be desired for a critical study of the steam-carbon reactions, water gas equilibrium, coke reactivities, catalytic effect of ash, conductivity of refractories, &c. It was possible, however, to obtain a good idea of the thermal efficiency of the process; and the author hopes to return to the other aspects of the work at a later date.

## SUMMARY AND CONCLUSIONS.

1.—A steady yield of blue water gas of calorific value 285 to 290 B.Th.U. gross can readily be obtained by steaming graded coke in a normal continuous vertical retort provided the correct conditions of:

(*a*) Quantity of steam,
(*b*) Rate of coke extraction,
(*c*) Quality of coke,
(*d*) Size of coke,
(*e*) Temperature,
(*f*) Exhauster "pull,"
(*g*) Gas tightness of retort,
(*h*) &c.,

are maintained. A calorific value of 290 to 300 is frequently obtained.

2.—The influences of the above factors are discussed and demonstrated in the experimental part of this paper.

3.—With suitable adjustments of the above factors the *following average data* have been obtained for a retort of which the nominal carbonizing capacity is 5 to 6 tons per day.

| — | Hourly. | Per 1 In. of the Mean Major Axis. | Per Longitudinal Strip of Retort Surface. (25 ft. by 1 in. mean width.) |
|---|---|---|---|
| Steam, lbs. . . . . | 190 | 3 | .. * |
| Coke extracted, lbs. . | 126 | 2 | .. * |
| Gas made, c.ft. . . . | 4600 | 73 | 36·5 |
| Thermal yield . . . | 13·3 | 0·21 | 0·105 |

* These figures would have little significance as they depend to a variable extent on the width of the retort. The reaction zone will consist of a layer of coke next to the retort walls, and will vary in thickness according to the quantity of steam, grade and quality of coke, &c., used

The coke was a mixture from horizontals and continuous verticals. The coals were from the Yorkshire, Derbyshire, and Nottinghamshire coalfields (or rich and moderate quality gas coals). Both coke oven and horizontal retort coke work well on the process.

The size of coke was our household grade—passing through a 2-in. screen (square mesh) and remaining on a 1¼-in. screen. It contained a small proportion below 1¼ in. owing to double handling.

The temperatures of the combustion flues were 1400° C. ± 10° C. at a position 7 ft. below the top of the brickwork and 1100° C. ± 10° C., 20 ft. below.

The exhauster "pull" on the retort was maintained at "level gauge" by an "Askania" governor (hydraulic relay type).

4.—A *thermal efficiency test* extending over 120 hours gave a result in which 58 p.ct. of the total heat in coke consumed in retorts *plus* gross coke to producers appeared as potential heat in the blue water gas, and showed that the waste gases could generate more than sufficient steam to be self-supporting (assuming a waste-heat boiler efficiency of 60 p.ct.). This 58 p.ct. compares favourably with the average result of 56 p.ct. for the orthodox intermittent process as given in the Sixth Report of the Gas Investigation Committee.*

Moreover, a test lasting 72 hours was run to determine the fuel necessary to maintain the retorts at a temperature of 1280° C. and 1080° C. in the top and lower parts of the combustion flues respectively with the retorts standing full of coke.

If the blue water gas process were used during scurfing time or while retorts were standing ready for carbonizing, it would be legitimate to consider only the fuel in addition to that needed to keep them hot; and then the efficiency in such circumstances rises to 69 p.ct. This allows for the fact that some steam must be raised by extra fuel (if waste heat from standing retorts was already being utilized for steam raising).

5.—*Effect on Total Thermal Output of Retort House.*—The process must be looked upon as a useful auxiliary to the working of verticals, and not as a substitute for the normal steaming process.

If coals are being used which can readily be steamed to give the desired calorific value, it would not be of any thermal advantage to make the blue water gas in a proportion of the retorts and reduce the steam on the others. By so doing we should lose the advantage derived from the heat in the coke, and the fuel consumption per therm would correspondingly rise. This limitation is clearly illustrated in the following calculation. We will assume:

(1) That we desire a gas of 475 B.Th.U. gross calorific value.

* British Patent No. 253702, May, 1925.

† "Investigation of Some of the Factors affecting Carbonization in Continuous Vertical Retorts." Trans. Inst. Gas Engrs., 1926.

* Trans. Inst. Gas Engrs., 1921, and "GAS JOURNAL," 1921.

(2) That a retort with steaming will carbonize a certain coal at 6 tons per day, giving 83·4 therms per ton of 475 calorific value; fuel consumption = 15·5 lbs. of coke per 100 lbs. of coal (both on dry basis); (single-stage process).

(3) That without direct steam (but approximately 5 p.ct. from quenching water) it will carbonize 7 tons per day giving 13,000 c.ft. of 540 calorific value = 70·2 therms per ton; fuel consumption, 13·7 lbs. of coke per 100 lbs. of coal (both on dry basis).

(4) One retort on blue water gas by graded coke makes 110,400 c.ft. per day of 290 calorific value and uses 22·62 lbs. of coke per 1000 c.ft. in the producers (see Experimental).

We then obtain the following comparisons between the single-stage and the two-stage processes:

The blue water gas necessary to dilute the rich coal gas of 540 to 475 = 4567 c.ft. per ton. The blue water gas from one retort on graded coke will therefore dilute the rich gas from 24·17 tons of coal = 24·17 ÷ 7 = 3·45 retorts. We have therefore to compare a retort house unit of 4·45 retorts working the normal single-stage process *versus* the two-stage process.

SINGLE-STAGE PROCESS.

Total therm yield = 4·45 × 6 × 83·4 = 2227 therms.
Total fuel . . = 4·45 × 6 × 22·4 × 15·5 = 9269
Fuel per therm = 4·16 lbs.

TWO-STAGE PROCESS.

Total therm yield = 3·45 × 7 × 13,000 × 540 = 1697 therms.
1 × 110,400 × 290 = 320
2017

Total fuel . . = 3·45 × 7 × 13·7 × 22·4 = 7417
110·4 × 22·62 = 2497
9914

Fuel per therm = 4·91 lbs.

6.—*Scurfing of retorts* by the process has been found possible, but takes longer than is economic where the amount of blue water gas desired is limited by a declared value of (say) 475 B.Th.U. gross. With the limit thus set, the process is not sufficiently reliable to adopt as a general routine. Such is our experience on a large works in Birmingham where 176 retorts were put on a water gas scurfing cycle for five weeks during the coal dispute.

The quantity and nature of scurf varies with (1) the class of coal, (2) throughput of coal, (3) amount of steaming, and (4) heat distribution and temperatures employed. Consequently it is not possible to generalize from the experience of one undertaking. It should, however, be borne in mind that retorts on 5 p.ct. of steam will produce more scurf than those on (say) 15 p.ct. of steam. The scurf from American coal was particularly difficult to steam off.

7.—*The cracking of gas oil* and production of carburetted water gas has been found to be a feasible proposition. Carburetted water gases of calorific values 375 and 447 B.Th.U. gross were obtained by using 0·97 and 1·86 gallons per 1000 c.ft. respectively. Inerts 13·1 and 13·7 p.ct.

8.—*The cracking of tar* proved very disappointing and impracticable. A lengthy series of tests showed very poor enrichment and led to nothing but trouble with blockages either in the retorts or in the seal pots, tar mains, and condensers. Carburetted water gases of calorific values 361 to 387 B.Th.U. gross were obtained by using 1·73 to 3 gallons per 1000 c.ft. respectively.

9.—*Depreciation of Extracted Coke.*—As might be anticipated, with coke from continuous verticals, depreciation was somewhat severe. The steaming made the coke very friable, and in addition to the concentration of ash it yielded a high percentage of material below $\frac{1}{16}$-in. screen—anything up to 33 p.ct.

If used in the producers, this would not cause any loss in value, and if sold in the coke market (preferably as a separate material) the loss in market value would probably be compensated for by the smaller quantity of dust made from the retorts carbonizing with reduced percentages of steam—two comparative 72-hour tests showed that with one particular coal, the quantity below $\frac{1}{16}$ in. was 7·6 p.ct. for 5 p.ct. steaming and 10·3 p.ct. for 23 p.ct. steaming.

Coke oven and horizontals coke only deteriorated to about one-third that of the above.

10.—*Effect on Refractories.*—When the setting was cooled down for repairs, the retort which had been water gas making for a considerable period showed no worse signs of deterioration than the other retorts in which relatively little blue water gas had been made.

11.—*Tightness of Retort.*—A year after the tests were carried out, the retort started to leak; and further tests demonstrated very strikingly that when steaming graded coke at the rate per hour equivalent to 15 p.ct. steam on a 6-ton throughput of coal, *i.e.*, 84 lbs./hour, it was impossible to prevent the ingress of flue gas inerts through leakages in the retorts. When slight pressure was put on the retorts, about half the "make" went through the leaks into the combustion flues. This emphasizes the need for keeping retorts tight when carbonizing in the ordinary way. The retort had been working for three years.

12.—*Practicability of the Blue Water Gas Process.*—The process can readily be put to work in a modern continuous vertical retort house, and with proper attention to governing, to maintain accurately "level gauge," there is no difficulty with outward leakage of poisonous gas and inward leakage of air to cause explosions. The normal amount of labour can look after the process quite comfortably.

13.—*Uses for which the Process is Suited:*

(*a*) As a balancing process to ensure maintenance of a uniform quality of gas in those retort houses obliged to use certain coals which are difficult to steam down to the desired calorific value, especially where such coals cannot be mixed with coals which work more easily (assuming also that the works does not usually run an ordinary blue water gas machine).

In such cases excessive steaming is necessary with calorific values below (say) 500, and the uncracked steam correspondingly high. The blue water gas process would give less uncracked steam, and thereby reduce steam bills, and the amount of effluent from ammonia stills.

From the author's experience, certain coals would show a reduction of 10 to 20 gallons per ton in the liquor.

(*b*) In certain circumstances it may be found useful for scurfing a proportion of retorts.

(*c*) In times of emergency, it can undoubtedly prove a useful adjunct for maintaining the gas supply at the expense of coke and gas oil.

(*d*) It can be applied to retorts which to meet sudden demands for gas are being kept almost at carbonizing heats.

(*e*) It can be used for regulating the coke market, and becomes in effect a complete gasification plant—the extracted coke being used as fuel.

## EXPERIMENTAL.

### PRELIMINARY CONSIDERATIONS.

Heat from the retort walls will be radiated into the coke and also carried to it by the currents of ascending steam and gases, which are repeatedly deflected to and from the heated walls as they encounter the lumps of coke.

Direct conduction of heat into the coke is likely to play a minor part with lump coke which only makes "point" contact with the walls (a useful conception of the path of the gases can be obtained by watching the behaviour of coloured currents of water ascending a glass cylinder filled with broken glass).

It seems likely, therefore, that the reaction zone is confined to a layer of broken coke next to the retort wall; the thickness of this layer depending on the temperature of the wall, the rate of steam, the grade and quality of coke, &c. The temperature gradient will fall from the wall towards the retort centre. The carbon consumed in each unit of retort space will depend upon the temperature and composition of the gases (including steam) passing through that space.

For these reasons it is impossible to get a clear picture of the course of the reactions from the analysis of the average products leaving the retort. This could only be obtained by determining the distribution of temperature in the coke and sampling the gases at various positions in the retort. There was no time for this interesting study.

The total "time contact" of the steam and gases in the retort was of the order of 17 seconds when using 190 lbs. steam per hour, assuming a uniform porous charge with gas passages equal to 50 p.ct. of the retort volume. Owing to the taper on the minor axis, and increase in volume due to the reaction, the time contact in the lower half was two to three times that in the top half.

### PARTICULARS OF PLANT, ROUTINE, &C.

The experimental work was all carried out on the

Birmingham Coal Test Works setting of four continuous vertical Woodall-Duckham silica retorts.

For the blue gas, and oil and tar cracking tests, one retort only was used; but for the thermal balance, heat loss test, and scurfing observations, all four retorts were used.

The retorts have a carbonizing capacity of 5 to 6 tons of coal per day per retort.

Full particulars of the retort dimensions and the many facilities for control and measurement of various items were given in a paper read before the Institution of Gas Engineers,* September, 1926.

No difficulty was experienced in feeding graded coke to the retort through the coal valve and auxiliary bunker.

The coke extraction was accomplished by working with the coke chamber filled with coke, and opening the bottom discharge door once per hour to allow about 1 cwt. of coke, or other desired quantity, to discharge —*i.e.*, the extraction was intermittent, and not continuous.

After preliminary tests had familiarized the staff with the necessary conditions for making blue water gas in the retorts, tests were carried out to discover the bearing of certain interdependent factors on the process; endeavour being made to vary one factor at a time, and to observe the results of each variation.

### Effect of Quantity of Steam.

Experiments Nos. 6, 7, 8, and 9 in Table I. were carried out with coke consisting of a mixture from horizontal (20 p.ct.) and continuous vertical retorts (80 p.ct.) graded for household purposes through a 2-in. square mesh screen and remaining on a 1¼-in. mesh. Owing to the additional handling in transporting to the test retort, the coke contained a small proportion of "fines" below 1¼ in.

The coke was extracted at a rate which preliminary experiments had shown to be useful.

The steam was introduced through a calibrated nozzle into the coke box.

The following points are noticeable:

(1) The temperature of the combustion flues falls progressively as the steam is increased, showing the cooling action of the steam. It was not possible to prevent the temperature falling with such amounts of steam.

(2) The $CO_2$ and $N_2$ increased with increasing steam, which may be attributable to one or both of the following:

(*a*) The reaction between CO and excess steam in an endeavour to establish the water gas equilibrium

$$CO + H_2O = CO_2 + H_2.$$

(*b*) The relative increase in the amount of reaction

$$C + 2H_2O = CO_2 + 2H_2,$$

due to decreasing temperatures.

(3) The thermal yield, quality, and make per hour show that no practical use is served in going beyond 205 lbs. of steam per hour.

Later experiments showed that the coke contains about 10 p.ct. of condensed steam under these conditions. Allowing for this, the percentage steam cracked has been calculated from the hydrogen figures.

### Combined Effect of Temperature and Distribution of Heats in Combustion Flues.

Tests Nos. 4, 5, 6, and 7 in Table I. were carried out at two temperatures using two quantities of steam at each temperature, and the same kind of coke. Both quantities of steam were too high for best practice. Only a few internal retort temperatures were taken; but these were carried out at a later date.

Comparing tests Nos. 4 and 7, a rise in the maximum flue temperature of 95° C., or in the average temperature of 120° C., gives an increase of 2·3 therms.

Comparing tests Nos. 5 and 6, a rise in maximum temperature of 67°, or an average temperature of 93°, gives an increase of 1·1 therm. The calorific value also improved with temperature.

In tests Nos. 7 and 6, not only were high maximum heats used, but they extended considerably higher up the combustion chambers.

### Effect of Size of Coke.

This point was not thoroughly explored; but the size 2 in. by 1¼ in. appears fairly satisfactory. Tests on a particular coke comparing the results with material 2 in. by 1¼ in. and 1¼ in. by ⅞ in. showed a decided advantage with the larger material.

Reactivity towards steam would have a bearing on the best grading to adopt.

### Effect of Rate of Coke Extraction.

The following points arise:

(1) Constant extraction means a constant replenishment of fresh coke, with its quota of more easily reactive carbon.

(2) The cool fresh coke extracts the heat from the exit gases and carries it back to the retort. This was clearly indicated by the records of temperatures of offtake gases.

(3) The dust formed by attrition and the action of steam is regularly removed by extraction, and keeps the charge from becoming choked.

From the results 15-16, 17-18, and 19 in Table I., an extraction of approximately 1 cwt. per hour appears satisfactory.

### Effect of Type of Coke.

Recent tests (a year later than the bulk of this work) with the harder cokes such as horizontal and coke oven coke show satisfactory yields of water gas of a reasonable quality.

Test D, Table I., was carried out on coke oven coke. There was considerably less deterioration in size of the coke. The low $CO_2$ and high steam open up interesting speculations on reactivity, porosity of charge, &c.

### Effect of Retort Leakage.

At the completion of test D on coke oven coke, the steam was dropped from 260 lbs. per hour to 78, which is equal to the rate when steaming at 15 p.ct. for a 6-ton coal throughput. This resulted in a rise in temperature and a serious increase in inerts, in spite

*"Investigation of some of the Factors affecting Carbonization in Continuous Vertical Retorts." "GAS JOURNAL," 1926.

TABLE I.

| Test | 4. | 5. | 6. | 7. | 8. | 9. | 15-16. | 17-18. | 19. | D. |
|---|---|---|---|---|---|---|---|---|---|---|
| Duration, hours | 9 | 27 | 24 | 22 | 13 | 12 | 32 | 28 | 24 | 20 |
| Coke, lbs. extracted per hour | 130* | 130* | 137 | 138 | 127 | 150 | 106† | 179† | 56† | 249‡ |
| Gas make, c.ft. per hour | 4372 | 4596 | 4921 | 5045 | 4708 | 4517 | 5276 | 5368 | 4866 | 5329 |
| Calorific value (calc.), gross per c.ft. B.Th.U. | 258 | 262 | 279 | 285 | 290 | 294 | 275 | 276 | 273 | 289 |
| Therms per hour | 11·3 | 12·0 | 13·7 | 14·3 | 13·7 | 13·3 | 14·5 | 14·8 | 13·3 | 15·4 |
| Analysis— | | | | | | | | | | |
| $CO_2$ | 13·6 | 13·3 | 10·0 | 8·1 | 6·0 | 3·9 | 8·0 | 8·1 | 9·3 | 4·1 |
| $O_2$ | 0·3 | 0·2 | 0·2 | 0·2 | 0·2 | 0·2 | 0·1 | 0·2 | 0·3 | 0·2 |
| CO | 27·1 | 27·7 | 24·8 | 34·5 | 37·3 | 40·2 | 34·8 | 34·7 | 32·6 | 43·5 |
| $CH_4$ | 0·2 | 0·1 | 0·3 | 0·2 | 0·2 | 0·1 | 0·3 | 0·3 | 0·1 | 0·5 |
| $H_2$ | 52·9 | 54·0 | 56·5 | 54·0 | 52·7 | 51·3 | 50·2 | 50·5 | 52·5 | 45·4 |
| $N_2$ | 5·9 | 4·7 | 3·3 | 2·1 | 3·2 | 4·3 | 6·6 | 6·2 | 5·2 | 6·3 |
| Steam, lbs. per hour | 261 | 316 | 316 | 261 | 205 | 178 | 188 | 188 | 188 | 260 |
| ,, p.ct. cracked‖ | 44 | 38 | 42 | 51 | 60 | 66 | 70 | 74 | 64 | 48 |
| Temps. combustion flues, ° C.— | | | | | | | | | | |
| 7 ft. down | 1000§ | 1000§ | 1361 | 1397 | 1399 | 1418 | 1396 | 1386 | 1379 | 1405 |
| 13 ft. ,, | 1302 | 1294 | .. | .. | .. | .. | .. | .. | .. | .. |
| 20 ft. ,, | 1050 | 1080 | 1076 | 1077 | 1093 | 1113 | 1088 | 1072 | 1041 | 1103 |
| Mean | 1117 | 1125 | 1218 | 1237 | 1246 | 1265 | 1242 | 1229 | 1210 | 1254 |

* Approximately. † Specially graded 2 by 1¼ from vertical retort, Nottinghamshire coal. ‡ Coke oven coke.
§ Approximately 1000° C. ‖ Allowing for 10 p.ct. condensation in the coke.

of the level-gauge conditions being first raised to 2/100-in. pressure (inerts 20·2 p.ct.) and then 4/100 in. water gauge (inerts 15·5 p.ct.). The make fell from 5329 to 2730 c.ft. per hour, and the thermal yield from 15·4 to 7·4. This was found to be due to leakage in the lower part of the retort, and illustrates the part played by steam in keeping out inerts.

When subsequently put on to carbonizing coal, more than half the steam, &c., was going into the combustion flues. The retorts are now shut-down for repairs, having worked a few years—sometimes under severe conditions.

The author would recommend the determination of moisture in producer gas and waste gases as a useful indication as to possible loss of steam, &c., through leakage (in conjunction with gas analysis).

### EFFECT OF STEAMING ON COKE QUALITY AND SIZE.

As one would expect, the average ash content in the extracted coke is increased and its structure weakened. With coke from continuous vertical carbonization, a considerable quantity of smalls is made. To test this point, the coke to retorts was carefully screened to size 2 in. by 1¼ in.; and then several batches of extracted coke over a 40-hour test (4 cwt. per 8-hour shift) gave the following average figures:

| | |
|---|---|
| Above 1¼ in. | = 31 p.ct. |
| 1¼ in. by ¾ in. | = 26·8 ,, |
| ¾ in. by $\frac{7}{16}$ in. | = 9·1 ,, |
| Below $\frac{7}{16}$ in. | = 33·0 ,, |

Total, 1 ton screened.

Similar deterioration was also noticed on the large works.

In connection with this problem, the effect on size of coke of normal steaming *versus* non-steaming was tried. Two tests, each three days, were run on the same coal, one with 18 p.ct. of steam and one non-steaming (water quenching). Samples every 8 hours were graded, and gave results:

| P.Ct. Steam Coal Throughput. | 18 P.Ct. Steaming 6·923 Tons per Day. | No Steaming 6 735 Tons per Day. |
|---|---|---|
| Above 5 in. | 0·8 | 0·8 |
| ,, 5 by 4 in. | 1·9 | 1·2 |
| ,, 4 by 3 in. | 5·2 | 6·9 |
| ,, 3 by 2 in. | 25·9 | 30·6 |
| ,, 2 by 1¼ in. | 29·9 | 29·2 |
| ,, 1¼ by ¾ in. | 20·0 | 18·3 |
| ,, ¾ by $\frac{7}{16}$ in. | 6·0 | 5·4 |
| Dust below $\frac{7}{16}$ in. | 10·3 | 7·6 |

The deterioration in size of coke oven coke has recently been shown to be about one-third the above.

Several screenings made during a 4-days' run using coke oven coke gave, on the extracted coke:

| | |
|---|---|
| Above 1¼ in. | 53·9 p.ct. |
| 1¼ by ¾ in. | 28·5 ,, |
| ¾ by $\frac{7}{16}$ in. | 6·0 ,, |
| Below $\frac{7}{16}$ in. | 11·6 ,, |
| Quantity graded | 0·8 ton |
| Original size | 2 by 1¼ in. |

### THERMAL EFFICIENCY AND HEAT LOSS TESTS.

In order to gauge completely the possibilities of the process, it was felt desirable to know the amount of fuel required per 1000 c.ft. of blue water gas, and to what extent the process would be self-supporting in the matter of supplying the necessary steam from the sensible heat in the waste gases.

It was also desirable to know the amount of fuel required to keep the setting either at scurfing temperatures or ready for carbonizing, because, if the blue water gas process were used at such times, it should be debited only with the coke extra to this amount.

Tests were accordingly carried out in which careful measurements and analyses were made of the following items:

(1) Weight of coke to and from retorts: Analyses and calorific values of same.
(2) Weight of coke to and from producers: Analyses and calorific values of same.
(3) Blue water gas: Volume, analysis, and offtake temperatures.
(4) Waste gas analysis and temperature leaving the setting.
(5) Quantity of steam to retorts.
(8) Temperature of combustion flues.

Items Nos. 1, 3, and 5 only apply to the blue water gas test.

The following data were obtained:

TABLE II.

| — | Blue Water Gas Test. Per 1000 C.Ft. | Heat Loss Test with Setting Standing at Scurfing Heat. Per Hour. |
|---|---|---|
| Duration, hours | 129 | 72 |
| Volume blue water gas, total c.ft. | 2,150,380 | .. |
| Volume blue water gas per retort per hour, c.ft. | 16,669 | .. |
| Calorific value blue water gas, B.Th.U. gross per c.ft. | 282·8 | .. |
| Dry coke to retorts | 44·43 | .. |
| Dry coke, calorific value, B.Th.U. gross per lb. | 12,510 | .. |
| Dry coke, ash content, p.ct. | 10·6 | .. |
| Dry coke from retorts, lbs. | 29 71 | .. |
| Dry coke, calorific value, B.Th.U. gross per lb. | *11,880 | .. |
| Dry coke, ash content, p.ct. | 15·8 | .. |
| Coke (carbon) consumed, lbs. | 14·72 | .. |
| Dry coke to producers, lbs. | 22·62 | 152·2 lbs. |
| Dry coke, calorific value, B.Th.U. gross per lb. | 12,491 | 12,410 |
| Dry coke, ash content, p.ct. | 11·0 | 11·7 |
| Dry coke in ashes *ex* producers, lbs. | 0·68 | 7 0 |
| Dry coke, ash content, p.ct. | 24·8 | 26·3 |
| Dry ashes, lbs. | 0·86 | 8·1 |
| Dry ashes, ash content, p.ct. | 66·8 | 73·5 |
| Dry clinker, lbs. | 0·82 | 5·2 |
| Dry clinker, ash content, p.ct. | 94·4 | 91·2 |
| Combustible matter consumed, lbs. | 19·32 | .. |
| Waste gas analysis, p.ct.—$CO_2$ | 18·8 | 9·6 |
| $O_2$ | 1·0 | .. |
| $N_2$ | 80·2 | 20·5 |
| Temperature waste gas, ° C. | 895 | 712 |
| Temperature offtake blue water gas, ° C. | 155 | .. |
| Steam to retorts, lbs. | 62·05 | .. |

* Calculated.

The approximate volume of waste gas was calculated on the combustible consumed, and its sensible heat content, as well as that of blue water gas, calculated by using the heat capacity formulæ compiled by the Gas Investigation Committee in Reports 4 and 7 (ref., "GAS JOURNAL," 1920 and 1922 respectively).

The uncracked steam was obtained by deducting the cracked steam (calculated from the hydrogen content) *plus* that condensed in the coke from the steam supplied.

The water content in the waste gas was unfortunately not determined. However, several subsequent determinations were made of uncracked moisture in the producer gas by passing 1000 c.ft. through a large water-cooled condenser. From these results and average complete analyses, it was found that the producer gas contained approximately 2·1 lbs. per 1000 c.ft. of uncracked steam, equal to 1·27 lbs. per 1000 of waste gas. Also that for an average hydrogen content of 10·3 p.ct. it made in addition 2·93 lbs. of steam in waste gas, equal to a total 4·2 lbs. per 1000 c.ft.

The following thermal balance-sheet was then compiled, representing therms per 1000 c.ft. of blue water gas.

TABLE IIa.

| | |
|---|---|
| Coke to producer | 2·825 |
| Coke consumed in retort | 2·053 |
| Fuel to raise steam | 0·989 |
| | 5·867 |
| Accounted for as— | |
| Water Gas { Potential heat | 2·828 |
| Water Gas { Sensible ,, | 0·046 |
| Steam not decomposed | 0·372 |
| Waste gas sensible heat | 1·324 |
| Heat lost in raising steam | 0·297 |
| Recovered coke | 0·069 |
| Ashes, potential heat | 0·038 |
| Clinker, ,, ,, | 0·006 |
| Losses, leakage, radiation, &c. | 0·887 |
| | 5·867 |
| *Efficiency of Gas Production, P.Ct.*— | |
| Fuel for steam taken into account | 48·2 |
| Fuel for steam not taken into account | 58·4 |

### OIL ENRICHMENT TESTS.

The retort was charged with graded vertical coke, size 2 in. by 1¼ in., and steamed for normal blue water gas production. Ordinary gas oil was introduced through two ¾-in. internal diameter pipes extending vertically down the centre of the retort on the major axis, equidistant from the ends of the retort, and the same distance from one another. The ¾-in. pipes were simply jacketted with 2-in. internal diameter pipe forming an annular space closed at the top, but open at the bottom.

This method of protection worked satisfactorily

without any need for introducing steam in the annular space.

If we assume that 1 gallon of gas oil gives approximately 87 c.ft. of oil gas and no inerts (see Seventh Report of the Gas Investigation Committee, "GAS JOURNAL," 1922), then the thermal yield per gallon equals approximately 1·25 as compared with 1·29 of the above report. The assumption must not be stressed, as the cubic feet of oil gas per gallon will depend on the oil and conditions of cracking. The thermal yield in Test 26 equals 528 therms per day. Apparently the same make could be enriched to (say) 475 B.Th.U., equal to 562 therms per retort per day. This compares with 540 therms from 6 tons of coal at 90 therms per ton, or 319 of blue water gas from graded coke.

### EXAMINATION OF RETORT FOR SCURF.

Prior to the oil cracking, the retort had worked 21 days on plain blue water gas, and was entirely free from scurf. After a total of six days on oil, it showed no signs of scurf, but it should be mentioned that twice during this period plain water gas was made between the oil tests.

**TABLE III.—*Oil Cracking Tests.***

[Specific gravity of oil = 0·842.]

| Test No. | 23. | 24. | 25. | 26. |
|---|---|---|---|---|
| Duration, hours | 24 | 24 | 16 | 20 |
| Coke, lbs. (approx.) extracted per hour | 120 | 120 | 120 | 120 |
| Gas make, c.ft. per hour | 4885 | 4857 | 4742 | 4925 |
| Calorific value, actual | 379 | 389 | 375 | 447 |
| Therms per hour | 18·5 | 18·9 | 17·8 | 22·0 |
| Analysis— | | | | |
| $CO_2$ | 7·9 | 6·9* | 6·0* | 6·5 |
| HC | 2 9 | 3 3 | 2·7 | 5·7 |
| $O_2$ | 0·2 | 0·3 | 0·2 | 0·2 |
| CO | 32·1 | 33 7 | 34·6 | 30·1 |
| $H_2$ | 47·5 | 46·8 | 49 6 | 41·2 |
| $CH_4$ | 3·8 | | | 7·9 |
| $N_2$ | 5·6 | 9·0 | 6·9 | 7·0 |
| Steam, lbs. per hour | 159 | 144 | 145 | 145 |
| Gas oil, galls. per hour | 4·99 | 5·05 | 4·57 | 9·15 |
| ,, ,, ,, ,, 1000 c.ft | 1·02 | 1·04 | 0·97 | 1·86 |
| Temperature of combustion flues, °C.— | | | | |
| 7 ft. down | 1000† | 1000† | 1000† | 1000 |
| 13 ft. ,, | 1311 | 1303 | 1320 | 1310† |
| 20 ft. ,, | 1089 | 1073 | 1067 | 1080 |

*Two analyses by special Orsat and two by Bone and Wheeler apparatus.
†Approximately 1000° C.
Steam measured by water evaporated.

When used on two retorts on our Nechells Works for several weeks during the coal dispute, the process apparently ran quite successfully, though towards the end of the period, large lumps of scurf made their appearance. It is probable that the inlet pipes were too far down the retorts.

### OIL TAR FROM TESTS.

These were insufficient for measurement purposes; but the following data indicate its nature.

| | |
|---|---|
| Specific gravity | 1·042 |
| $H_2O$ | 46·0 p.ct. |
| Free carbon | 1·8 p.ct. dry basis |
| *Distillation of Dry Tar.* | |
| 0° to 170° C. | 3·0 p.ct. |
| 170° to 230° C. | 8·6 ,, |
| 230° to 270° C. | 10·4 ,, |
| 270° to 330° C. | 8 6 ,, |

The fractions 170° to 270° were saturated with naphthalene.

### TAR CRACKING TESTS.

In the first series of tests (Nos. 27 to 33, Table V.) vertical retort tar from a heated overhead tank was introduced at various depths and rates through two ¾-in. internal diameter pipes. These pipes were jacketted with 2-in. piping, but no steam or water was used in this jacket.

The retort was working on vertical coke (grade 2 in. by 1¼ in.) from one type of coal, and the tar used was vertical tar from the same coal, containing about 5 p.ct. of water. Minor difficulties arose with the tar feed to the pipes; but these troubles were as nothing compared with the "pitching-up" of the tar pot and tar mains.

These were blocked with solid pitch, and had to be dismantled and burned out. Continuation of the tests was made possible only by continually ladling out the pitchy tar from the tar pot on the retort offtake.

During these tests about 60 p.ct. of the tar was "cracked" to gas and coke.

**TABLE V.**

| Tar to Retort. | | Tar in Tar Pot. | Pitchy Deposit. |
|---|---|---|---|
| Specific gravity | 1·069 | 1·181 | 1·218 |
| Free carbon | 2·7 | 13·3 | 9·2 |
| | | | Twisting point, 14° C. |
| | | | Melting point, 40° C. |
| Distillation— | | | |
| °C. | P.Ct. | | |
| 110 | 2·6 | .. | .. |
| 200 | 9·9 | 6·0 | .. |
| 220 | 16·6 | .. | .. |
| 240 | 24·5 | 8·0 | .. |
| 260 | 30·4 | 10·0 | .. |
| 280 | 34·4 | .. | .. |
| 300 | 38·5 | 14·0 | .. |
| 320 | 42·4 | 20·0 | .. |

### REMARKS ON SERIES 1.

*Test* 27.—Tar feeds blocking-up. Variation in temperatures of tar and separation of water in overhead tank caused difficulty.

*Test* 28.—Tar feeds blocking-up. Variation in tem-

**TABLE IV.—*Tar Cracking in Conjunction with Water-Gas Production.***

| — | Series I. | | | | | | Series II. | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Test No. | 27. | 28. | 29. | 30. | 31. | 32. | 33. | 35. | 36. | 37. | 38. | 39. | 40. | 41. |
| Duration, hours | 24 | 16 | 24 | 24 | 24 | 24 | 16 | 22 | 16 | 18 | 18 | 16 | 16 | 10 |
| Coke[1], approx. lbs. extracted per hour | 120 | 120 | 120 | 120 | 120 | 120 | 120 | 280 | 336 | 280 | 280 | 270 | 280 | 280 |
| Gas make c.ft. per hour | 4474 | 4350 | 4587 | 4670 | 4683 | 4780 | 4709 | 3798 | 4106 | 4555 | 4556 | 4228 | 3733 | 3535 |
| Calorific value[2], actual B.Th.U. gross/c.ft. | 361 | 355 | 340 | 330 | 327 | 318 | 387 | 332 | 372 | 354 | 353 | 347 | 372 | 362 |
| Therms per hour | 16·1 | 15·4 | 15·6 | 15·4 | 15·3 | 15 2 | 18·2 | 12·6 | 15·2 | 16·1 | 16·1 | 14·6 | 13·9 | 12·8 |
| Analysis[3]— | | | | | | | | | | | | | | |
| $CO_2$ | 6·4 | 6·2 | 5·9 | 6·0 | 5·1 | 6·3 | 8·9 | 8·7 | 9·1 | 10·8 | 10·8 | 10·6 | 10·0 | 12·9 |
| HC | 1·3 | 1·4 | 1·0 | 1·1 | 0·9 | 0·9 | 2·0 | 1·1 | 1·4 | 0·8 | 0·9 | 0·6 | 1·4 | 1·5 |
| $O_2$ | .. | 0·2 | 0·2 | 0·2 | 0·2 | 0·2 | 0·5 | 0·3 | 0·6 | 0·2 | 0·2 | 0·1 | 0 2 | 0·6 |
| CO | 35·4 | 35·4 | 37·3 | 35·1 | 37·3 | 36·1 | 27·5 | 27·7 | 24·9 | 24·5 | 21·9 | 23·0 | 23·5 | 20·6 |
| $H_2$ | 45·3 | 50·3 | 44·1 | 50·6 | 49·8 | 46·5 | 49·5 | 55·8 | 53·5 | 55·0 | 59·9 | .. | 56·6 | 53·9 |
| $CH_4$ | 6 6 | 3·3 | 6·0 | 1·5 | 1·8 | 2·9 | 6·4 | 3·0 | 6·8 | 6·3 | 3·9 | .. | 4·9 | 6·2 |
| $N_2$ | 5·0 | 3·2 | 5·5 | 6·5 | 4·9 | 7·1 | 5·2 | 3·4 | 3·7 | 2·2 | 2·4 | 2·2 | 3·4 | 4·3 |
| Steam, lbs. per hour, top | .. | .. | .. | .. | .. | .. | .. | 40 | 40 | 40 | 40 | 58 | 40 | 30 |
| ,, ,, ,, bottom | 144·5 | 145 | 144 | 145 | 145 | 145 | 144 | 137 | 135 | 137 | 135 | 108 | 137 | 160 |
| Dry tar, galls. per hour | 7·7 | 9 4 | 8·2 | 7·9 | 8·5 | 9·1 | 14 2 | 16·0 | 13·6 | 11·9 | 13·0 | 11·4 | 13·5 | 13·5 |
| ,, ,, ,, 1000 c.ft. | 1·73 | 2·18 | 1·77 | 1·70 | 1·81 | 1·9 | 3·0 | 4·20 | 3·31 | 2·61 | 2·85 | 2·69 | 3·6 | 3·8 |
| Temps. of combustion flues— | | | | | | | | | | | | | | |
| 7 ft. down | 1000* | 1000* | 1000* | 1000* | 1000* | 1000* | 1000* | 1000* | 1000* | 1000* | 1000* | 1000* | 1337† | 1341† |
| 13 ft. ,, | 1333 | 1327 | 1334 | 1329 | 1325 | 1329 | 1323 | 1285 | 1301 | 1300 | 1322 | 1309 | .. | .. |
| 20 ft. ,, | 1082 | 1089 | 1100 | 1097 | 1092 | 1085 | 1100 | 1082 | 1070 | 1069 | 1057 | 1058 | 1058 | 1033 |
| Position of pipes (ft. below top of brickwork) | 4 | 4 | 4 | 4 | 3 | 3 | 4 | 4 | 6 | 8 | 10 | 10 | 6 | 6 |

[1]. Well-graded vertical coke from one type of coal 2 in. by 1¼ in. [2]. By Junkers calorimeter on 10 c.ft. sample from offtake of retort.
[3]. By Bone-Wheeler apparatus. * Approximate temperature of 1000° C. † These temperatures were on top heating.
Steam measured by water evaporated.

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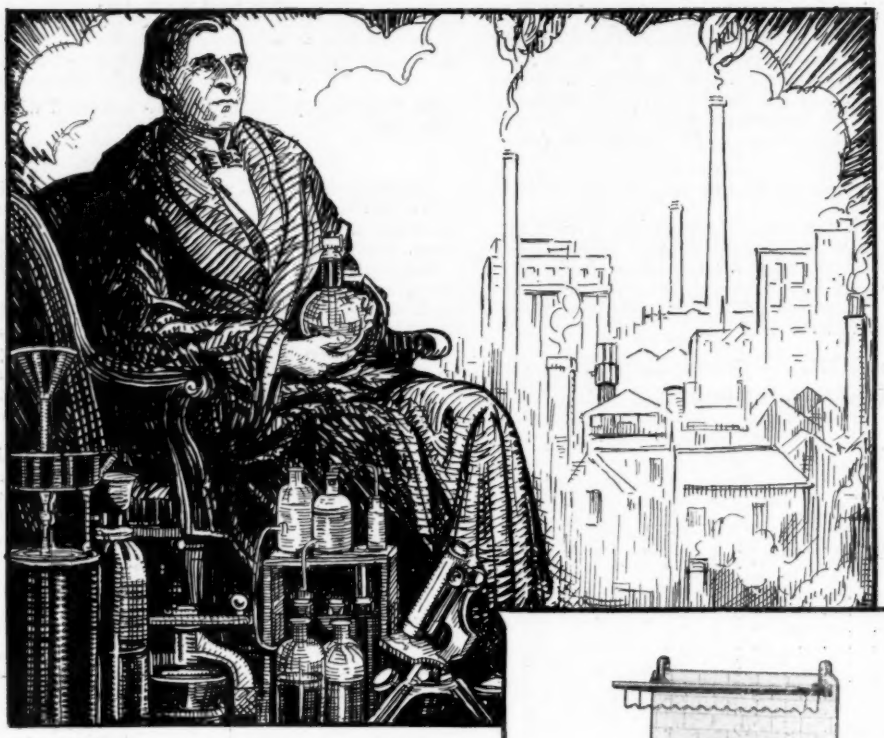

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peratures of tar and separation of water in overhead tank caused difficulty.

*Test* 29.—Tar pot run off on outlet retort, and tar mains blocked solid. Dismantled and burned clean. Ladling thick hot tar from tar pot.

*Tests* 30, 31, and 32.—Tar pot run off on outlet retort, and tar mains blocked solid. Dismantled and burned clean. Ladling thick hot tar from tar pot.

*Test* 33.—Offtake tar still pitchy, in spite of doubling the rate of supply.

*State of Extracted Coke.*—This showed marked evidence of pitch coke, and the cementing together of coke pieces.

*State of Retort.*—The retort was emptied and examined after the last test, and found to be free from scurf.

The retort was then put on to a mixed coke containing 80 p.ct. vertical and 20 p.ct. horizontal (grade 2 in. by 1¼ in.). Further tar tests were made using mixed tar in the same proportions.

Attempts were then made to introduce the tar with the pipes lower down the retort—*i.e.*, 6 ft. below brickwork—hoping that it would be completely cracked to gas and coke, and thus avoid the pitch trouble in the tar mains. Steam was injected along with the tar, primarily to prevent the ¾-in. pipes becoming blocked in the hot zone.

Trouble soon developed in another direction. The retort started to show serious bottom pressure, and the make fell from 4800 c.ft. per hour to 200—almost ceasing. This was with 20 gallons of tar per hour.

After vigorous rodding, the charge was got on the move again, and tar at 10 gallons per hour was used; but the same trouble recurred.

Similar results were obtained with the pipes 4½ ft. below top of brickwork.

The retort had to be emptied; and it took many hours of hard work to dislodge the block of concrete-like coke.

After recharging, the tests were repeated, and it was found possible to proceed by extracting the coke at two to three times the normal speed. This kept the charge on the move, but large agglomerations of coke were still very much in evidence.

The next serious trouble occurred in the foul main, condensers, and exhauster, which all became blocked with naphthalene.

The idea of further testing was abandoned.

The results of the second series, Nos. 35 to 41, are given in Table V.

Apart from the practical difficulties, it will be seen that the thermal yield varied from 302 to 437 therms per day, as compared with 319 when making blue water gas.

In conclusion, the author desires to thank Mr. A. W. Smith, General Manager and Secretary, and the Gas Committee, for permission to publish this paper. His thanks are also due to Mr. W. J. Pickering, A.I.C., Coal Test Plant Superintendent, and Mr. E. Branson, Staff Foreman.

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**Paper L. Session IV.**

# A Consideration of the Properties of Silica and Fireclay Products in Relation to the Carbonizing Industries.

**By A. T. GREEN, F.Inst.P., A.M.I.Chem.E.**

## INTRODUCTION.

An important feature of the trend of modern carbonization appears to be the increasing temperature of working, the objects of which are reported as the realization of larger throughputs and greater speeds of working. This feature, together with the necessity for flexibility of working, puts a great tax on an installation, and, in fact, necessitates a plant capable of withstanding comparatively drastic conditions.

For all carbonizing operations, the material of construction must be refractory to heat at the temperatures of working, and to other influences which will be defined later. It must maintain itself as a structural entity during working and give a life long enough to ensure the complete economy of the process. It should possess, as far as is possible, thermal properties capable of giving increased efficiency to the process of carbonization. This definition of the required attributes is fundamental. It contains the *sine qua non* of the position. With the increasing duties of modern working, materials which were considered capable of satisfying the demands of the older practice are said to be losing their potency. It is reported that such products cannot give a satisfactory compromise of the above requirements when applied to modern conditions. In the following pages it is hoped that some explanation of this state of affairs, together with an indication of the limitations of economic refractories under "carbonizing" conditions, will be found.

## THE TEXTURE AND CONSTITUTION OF FIRECLAY, SILICEOUS, AND SILICA PRODUCTS.

### *Fireclay Products.*

Fireclay is a comprehensive term, including a large variety of substances, differing to a considerable extent in both constitution and physical properties. The essence of clay is often conveniently referred to as "clay substance," which in its crystalline form is known as kaolinite, but when it exists as a colloidal, non-crystalline material, Mellor[1] has termed it clayite. The commonly accepted formula for clay substance is $Al_2O_3.2SiO_2.2H_2O$. Besides this compound, fireclay contains variable quantities of accessory minerals, including quartz, micas, felspars, iron and lime bearing minerals. As a matter of convenience it is desirable to consider the constitution of fireclays in terms of clay substance, quartz, felspathic and micaceous, ferruginous (ferrous and ferric), calcareous, and carbonaceous substances. Such a conception helps particularly in comprehending many phenomena associated with the firing and ultimate properties of fireclay products, including the vitrification, the colour and formation of "iron" blebs and patches, and the texture of the finished product.

In the manufacture of firebricks the raw materials are subjected to preliminary treatments, including mixing, grinding, screening and tempering. Depending on the nature of the clay, varying quantities of graded grog (15 to 25 p.ct. of pre-fired fireclay), the very fine fractions of which have been eliminated, are added, and then worked into the clay in order to obtain a homogeneous mixing. This initial treatment is of great importance, since if it is inadequate the texture of the brick may be ruined. For instance, a laminated texture is particularly objectionable, since a product possessing it is liable to "spalling." The fireclay shapes, after being properly dried, are fired according to a predetermined schedule. During firing, many properties of the product are determined. Thus the oxidation period (500° to 850°) is mainly concerned with the elimination of carbonaceous matter, the oxidation of iron compounds, the breakdown of carbonates, sulphides, and other compounds, together with the decomposition of the clay molecule with the evolution of the water of constitution. At this stage, then, many properties are determined. The formation of "blackcores" and "iron centres" have their origin in the inaccurate control of oxidation or the preliminary operation of water-smoking.

In an investigation concerning the detrimental

effects of "blackcores," the present author noted the difference in porosity of a number of samples of products made from the same fireclay at the same time and in the same manner, showing this defect in varying degrees. This is indicated in Table I.

TABLE I.

| — | Description of Material. | Exterior Portion of Brick. P.Ct. Porosity. | Interior Portion of Brick. P.Ct. Porosity. |
|---|---|---|---|
| A. | Well fired, even coloured product showing no coring. . | 23·8 | 25·9 |
| B. | Similar to A. . . . . | 23·7 | 25·5 |
| C. | Reddish brown interior suggesting first stage of coring | 23·6 | 21·3 |
| D. | Dirty brown core . . . . | 22·6 | 20·2 |
| E. | Over-fired appearance, cored interior very vitrified . . | 17·1 | 14·3 |

It is obvious that because of the extra vitrification consequent on the formation of the core in the interior, the brick is definitely strained, while it is sometimes warped or cracked from the same cause.

The final period of firing, ranging from 850° C. to the finishing temperature, is known as the vitrification range. Vitrification may be defined as the progressive partial fusion of some of the mineral constituents of the fireclay, chiefly including felspathic, calcareous, and ferruginous substances. It is governed among other factors by the composition of the body as a whole, the size of the grain, and the desired structure of the ware. In fact, the object of the heat-work during this period is the production of a suitable amount of vitrified or glassy material which will surround the remaining particles and fill the interstices to a suitable extent, dependent on the properties desired in the finished product. At the commencement of this period, the most fusible silicates begin to melt, and, also, melting silicates are formed. These silicates become more fluid with rise of temperature, and commence to dissolve other constituents, which event generally reduces the fluidity. Many physico-chemical phenomena, including the effect of eutectic mixtures and the formation of complex substances, are now brought into play, and these influence profoundly the physical properties and chemical constitution of the viscous mass. The art of correct firing consists in manipulating the vitrification so that the final product possesses a desirable compromise of properties.

During vitrification and the subsequent cooling period, a certain crystallization phenomenon takes place, which appears to have a most important influence on the properties of fireclay products. Hyslop[2], among others, has stated that in the neighbourhood of 1000°, a compound having the formula $3Al_2O_3.2SiO_2$, known as mullite, is formed. Some workers prefer to consider this compound as sillimanite, $Al_2O_3.SiO_2$. It is, however, fairly definite that exceedingly minute crystals do appear in the neighbourhood of 1000° to 1050° C., and that their number and size increase with increasing heat-work in the vitrification range. In many instances, X-ray examination is necessary to show these crystals. Ennos and Scott[3], however, say that the micro-examination of fireclays fired to temperatures over 1100° C. shows the presence of numerous acicular crystals usually set in a glassy matrix. Many factors—temperature, time, and the nature of the matrix present during vitrification—influence the formation of mullite. The effect of the matrix is particularly intriguing, for there appears to be a definite connection between the solubility of quartz in this viscous entity and the amount of crystallization of mullite from it.

Table II. shows the ultimate and the proximate analyses of several British fireclays.

TABLE II.

| — | No. 1. | No. 2. | No. 3. | No. 4. | No. 5. |
|---|---|---|---|---|---|
| $SiO_2$ . . . . . | 47·10 | 54·36 | 63·00 | 73·76 | 40·18 |
| $TiO_2$ . . . . . | 0·16 | 1·39 | 0·21 | 0·46 | 1·21 |
| $Al_2O_3$ . . . . | 38·42 | 28·69 | 22·00 | 16·44 | 45·04 |
| $Fe_2O_3$ . . . . | 0·20 | 2·37 | 1·23 | 1·47 | 1·18 |
| CaO . . . . . | 0·25 | 0·56 | 0·81 | 0·58 | 0·01 |
| MgO . . . . . | 0·16 | 0·49 | 0·24 | 0·16 | 0·01 |
| $K_2O$ . . . . . | 0·16 | 2·24 | 2·15 | 1·94 | 0·84 |
| $Na_2O$ . . . . | 0·08 | 0·60 | 1·02 | 0·56 | 0·48 |
| Loss on ignition | 13·10 | 10·90 | 9·82 | 5·82 | 11·31 |

*Calculated Proximate Analyses.*

| — | No. 1. | No. 2. | No. 3. | No. 4. | No. 5. |
|---|---|---|---|---|---|
| Clay substance. . | 95·4 | 66·4 | 44·1 | 34·8 | 75·5 |
| "Free" silica . . | 0·3 | 22·9 | 26·4 | 48·5 | .. |
| Felspar . . . | 3·8 | 10·1 | 24·9 | 14·8 | 7·8 |
| Iron oxide . . . | 0·2 | 2·4 | 1·2 | 1·5 | 1·2 |
| "Free" alumina . | .. | .. | .. | .. | 13·8 |

These analyses indicate that, generally, fireclays contain clay substance and quartz in very variable quantities. In fact, it has been suggested that fireclays may be divided into three categories: (1) Normal, with an alumina content between 36 and 39 p.ct.; (2) aluminous, containing over 39 p.ct.; (3) siliceous, containing less than 36 p.ct. of $Al_2O_3$. The "siliceous" fireclay is by far the commonest category, and it is often taken to include that variety of product in which quartz is added as an addition or reinforcement.

It is a well-established fact that siliceous fireclays contain free quartz varying in grain size from submicroscopic particles to grains of appreciable magnitude. The "free" silica computation gives an indication of the relative quantity of this mineral. After the moderate kiln firing to which fireclay products are subjected, much of this quartz may remain as such embedded in the matrix or supporting structure of the fired product. Depending on the duration of the fire, the size of the grain and the nature of the matrix, some of the quartz may be transformed into cristobalite. It does not necessarily follow, however, that high quartz content in a raw material will produce high quartz or cristobalite content in the fired product. Much depends on the grain size, the amount, distribution and nature of the fluxing materials, and the firing procedure. Some quartzitic material may go into solution in the viscous flux during vitrification, and remain in this state after cooling. Dissolved quartz behaves rather as silica glass, and does not show the characteristic expansion of quartz and cristobalite. Other quartzitic particles may be transformed into cristobalite, while some maintain their identity. Table III., which is due to Geller[4], shows the results of petrographic examination of samples of fireclays which have undergone varying heat treatments.

TABLE III. *Results of Petrographic Examination*

| Firebrick No. | As Received. | Refired at 1400° C. for 5 Hours. | Refired at 1150° C. for 72 Hours. |
|---|---|---|---|
| 6 | 35 p.ct. quartz, no cristobalite, some mullite | Some cristobalite, more mullite | 20 to 25 p.ct. cristobalite, extensive mullite |
| 7 | 75 p.ct. quartz, quartz grog, no mullite | Some shattering of quartz and slight cristobalite, some mullite | 70 p.ct. cristobalite, well formed crystals of mullite |
| 41 | 20 to 25 p.ct. quartz, no cristobalite, considerable mullite | Most of quartz has changed to cristobalite, extensive formation of mullite | Quartz entirely converted to cristobalite. Mullite development very extensive |

Thus, in a siliceous firebrick the silica may be present as (1) free quartz, (2) cristobalite, and (3) dissolved silica, or (4) any combination of these three modifications. Constitutionally, then, a fireclay product may contain mullite, quartz, cristobalite, corundum (derived from excess alumina), and a matrix of vitrified material.

### *Texture of Fireclay Products.*

The texture of a fireclay product is controlled by (1) the grain size of the clay; (2) the nature and grading of the grog addition; (3) the extent of the firing operation. Fineness of grain favours vitrification and so reduces the refractoriness or heat resisting capability of the material. Consequently, it may be taken as axiomatic that the coarser the texture of a firebrick made from an individual fireclay, the higher its softening temperature.

Grog may be regarded as burnt fireclay or ground firebrick which is mixed with fireclay to serve as a skeleton to facilitate drying, to control the contraction during drying and firing, and to modify the behaviour of the refractory material when in use. The meaning of the term "grog" is also extended to include non-plastic materials other than burnt fireclay. Grog be-

haves as an independent constituent and is fixed in the brick by the fluxes of the surrounding clay. This state lasts until the firing or high temperature use has been so excessive as to destroy the distinctive character of the grog.

As already mentioned, the refractoriness of a coarse-grained product is greater than that of a fine-grained one, other factors being equal. Further, the tendency of the coarse-grained brick to crack and split with abrupt changes of temperature is much less than that of a fine-grained product. The crushing strength and tenacity of a coarse-grained brick are, however, always low. Thus, gas-retort sections with a feeble tensile strength are very friable and readily disintegrated by shocks, abrasion, and such actions. The pores of the coarser products are generally large, with the result that flue dust and slag penetrations rapidly take place in practice. Thus it appears clear that with such antithetical properties for these two types of products it is often desirable to compromise.

### *Silica Products.*

Quartzitic rock—*i.e.*, ganister—forms the usual basic raw material used in the manufacture of "straight" silica bricks. Such rock is crushed, ground, graded, mixed, and "tempered" with lime emulsion so that the final product contains about 2 p.ct. of lime. After moulding into shape, the products are fired to high temperatures in the vicinity of Cone 16 (1460°).

The texture, and in some measure the final constitution, of a silica product are determined by the grading of the original raw material. In fact, there is an immense field for investigation in the problems connected with the influence of grading on the constitution and successful usage of such materials.

Table IV. gives the screen analyses of seven well-known British silica bricks in the unfired state.

TABLE IV.—*Percentage Screen Analyses.*

| Screens . . . | A. | B. | C. | D. | E. | F. | G.* |
|---|---|---|---|---|---|---|---|
| On 6's . . . | .. | 13·8 | 0·3 | 3·7 | 10·0 | 4·0 | 1·0 |
| On 20's . . . | 13·3 | 28·4 | 2·5 | 31·6 | 29·0 | 34·5 | 4·0 |
| On 60's . . . | 19·4 | 6·5 | 33·5 | 22·5 | 20·4 | 23·0 | 22·5 |
| On 120's . . | 13·8 | 16·1 | 43·0 | 15·3 | 14·7 | 12·5 | 25·0 |
| Through 120's . | 53·3 | 35·2 | 21·0 | 26·3 | 26·0 | 26·0 | 47·0 |

* Brick made from "pocket-sand" bonded with clay, and not lime.

An examination of this table shows that there is a great difference in the texture of bricks which are often used for similar purposes. Thus, A, B, C, and G find wide application in coke oven and gas retort construction, while E is used for the roofs of steel furnaces. In general, it is found that a "fine" texture is more effective in the carbonizing industries. In the manufacture of straight silica bricks, the mechanical strength of the material depends on the nature of the coarser fragments (*i.e.*, their angularity, the amount of the fine fraction, and the firing treatment). Fragments of high angularity with about 40 p.ct. of "fines" and an adequate firing in the neighbourhood of Cone 16 produce a strong brick. The "flour" of silica—*i.e.*, the fine fraction—is of first-rate importance, since it determines the matrix formation and the alteration of the silica, both of which phenomena take place during the high-temperature period of the firing.

The constitution of silica products is determined, in the main, by (1) the nature of the original raw materials (*i.e.*, ganisters and sands); (2) the manufacturing procedure, particularly respecting the grading of the raw materials, and the nature and amount of flux used, which is generally hydrated lime; (3) the control and extent of the firing operation. Silica has the property of existing in several crystalline modifications, the physical properties of which differ widely. Quartz, which is the stable modification at ordinary temperatures, may, at high temperatures (over 1000° C.), be transformed into either or both of two other forms—*i.e.*, tridymite and cristobalite. These changes are accelerated by the presence of a flux such as lime, which is the common agent used in the manufacture of silica bricks. Such an acceleration appears to be due to the solvent action on silica particles of a viscous complex calcium silicate formed primarily by the interaction of lime and finely divided silica. The solvent action is followed by the precipitation of the dissolved silica in the form of cristobalite. In any well-burned, lime-bonded silica bricks, tridymite, cristobalite, and quartz, together with 5 to 15 p.ct. of a glassy matrix of a complex calcium alumino-silicate, may be present. The most drastic firing of "straight" silica bricks aims at the total elimination of quartz, and, as far as is compatible with the cost of continued firing, the production of an excess of tridymite. For coke ovens and gas retorts, those straignt silica bricks which have received adequate firing are certainly the most successful.

The elucidation and quantitative expression of the constitution of a silica brick is not a simple matter. While there are investigators who believe in the efficacy of the microscope in the detection of the relative amounts of the three forms, there are others who cannot accept this point of view, owing to the very slight differences in the optical properties of tridymite and cristobalite. The specific gravities of these two forms are very near to each other, and thus the determination of density, while affording a valuable clue as to the amount of conversion of quartz into one or both forms, does not give any guide concerning the relative amounts of these two conversion products.

The specific gravity of quartz is 2·65, of cristobalite 2·32, and of tridymite 2·28. Any straight silica brick, then, which has a true specific gravity of over 2·50 is poorly-fired and contains a large proportion of quartz. The medium-fired product has a specific gravity of 2·42, and, in consequence, contains an appreciable quantity of quartz, together with some cristobalite. In a high-grade product, which has a specific gravity varying from 2·32 to 2·37, the quartz content has been reduced to a practical minimum. These bricks, however, contain variable quantities of tridymite and cristobalite—a fact which plays a conspicuous part in the low-temperature spalling tendency.

Table V. gives some of the physical data concerning well-known brands of British silica bricks (where the letters correspond to Table IV., the same brands of product are indicated).

TABLE V.

| Mark. | Analysis. | | | Physical Data. | | |
|---|---|---|---|---|---|---|
| | $SiO_2$. | $Al_2O_3$. | CaO. | True Sp. Gr. | App. Sp. Gr. | True P.Ct. Porosity. |
| A . . | 95·80 | 1·18 | 1·46 | 2·336 | 1 69 | 27·9 |
| B . . | 95·00 | 1·58 | 2·34 | 2 319 | 1·60 | 31·0 |
| C . . | 94·68 | 1·26 | 3·20 | 2·327 | 1·40 | 39·8 |
| E . . | 95·04 | 0·83 | 1·62 | 2·356 | 1·71 | 27·6 |
| F . . | 94·20 | 1·80 | 1·48 | 2·438 | 1·73 | 29·1 |
| G* . . | 91·50 | 5·87 | 0·34 | 2·52 | 1·90 | 26·1 |
| H . . | 94·54 | 2·93 | 1·35 | 2·371 | 1·66 | 30·1 |
| I . . | 95·00 | 1·74 | 1·54 | 2·345 | 1·53 | 34·8 |

*G. Pocket-sand product.

Micro-examination and other data have indicated that B and C contain high percentages of tridymite, whereas A, H, and I contain large cristobalitic developments. This is interesting in the light that B and C contain large amounts of lime and show the greater development of matrix. Further, there can be little doubt that these products have received very effective heat treatments. While it is unsafe to generalize, the author has noted that the larger amounts of lime, together with effective firing, have usually resulted in an increase of tridymite. Naturally there is a limit to the amount of the lime addition, high percentages tending towards the production of a larger amount of matrix, which becomes comparatively fluid and causes softening at high temperatures. Such a softening may be advantageous or otherwise according to its degree. Thus, if the softening is too excessive the structure loses some of its stability; while in other cases, a desirable amount of viscosity of the matrix may serve to take up that strain, induced by any changes of quartz to other low specific gravity forms during industrial usage. It is obvious, then, that in general the matrix formation must not be too great, and the matrix itself must possess that viscosity which will ease strain in the structure without undue softening.

Figs. 1 and 2 represent microphotographs of the matrices of two silica bricks. One shows the acicular cristobalitic patterns, the other tridymite in a large quantity of glass.

The determination of the variation of the coefficient of thermal expansion of a silica brick with temperature gives some indication of its constitution. There are, of course, limitations to the inferences which can be drawn from expansion determinations, since there are certain indeterminate factors to be considered. Quartz, cristobalite, and tridymite are themselves capable of existing in more than one form. The changes from one form to another—*i.e.*, from the $\alpha$ to the $\beta$ state—are known as inversions, and take place in a

reversible manner at relatively low temperatures. Fenner[5] writes these inversions as follows:

$$\alpha \text{ quartz} \overset{575^\circ}{\rightleftharpoons} \beta \text{ quartz}$$

$$\alpha \text{ cristobalite} \overset{225^\circ}{\rightleftharpoons} \beta \text{ cristobalite}$$

$$\alpha \text{ tridymite} \overset{117^\circ}{\rightleftharpoons} \beta_1 \text{ tridymite} \quad \beta_2 \overset{163^\circ}{\rightleftharpoons} \text{tridymite}$$

These changes are associated with very appreciable volume alterations, the largest of which, according to some investigators, amounts to 3 p.ct. of the original volume of the brick. Such inversions may cause severe strains in the product, ending in final disruption. Table VI. gives data concerning the expansions noted for the reversible changes under consideration.

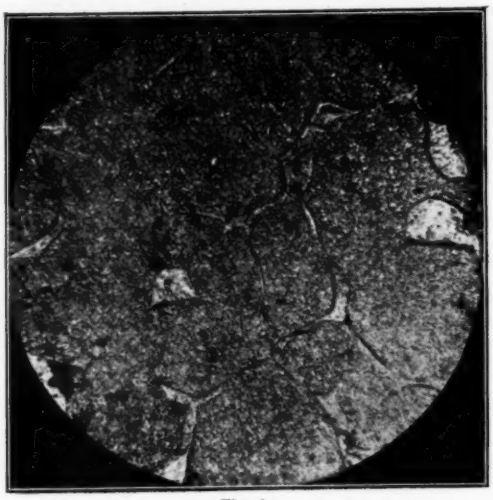

Fig. 1.

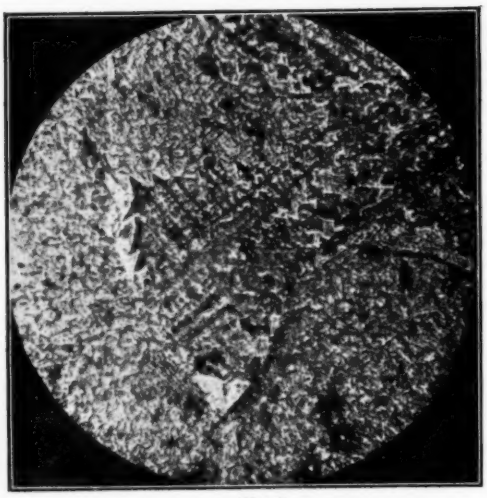

Fig. 2.

The data of this table show the appreciable differences in the volume changes of the three inversions, and indicate that a measure of such expansions must give some information respecting the relative amounts of the different forms present in a particular material. The present author[8], in collaboration with H. Edwards, in a consideration of the tridymite and cristobalite changes, but not that due to the presence of quartz, has completed some work on this aspect. The product was tested in the form of a small cylindrical specimen at a number of rates of rise of temperature. The results reported in Table VII. give the figures for a very slow rate of rise of temperature; the temperatures being measured on the surfaces of the specimens.

TABLE VI.

| $SiO_2$ Modification. | Increase in Volume (V). Increase in Length (L). | Investigator. |
|---|---|---|
| to quartz . . . | 0·45 p.ct. (L) | Fenner |
| α cristobalite . . | 1·0 p.ct. (L) | Fenner |
| to β cristobalite . . | 3·5 ,, (V) | Spotts McDowell[6] |
| | 2·0 ,, (V) | Endell and Rieke[7] |
| α tridymite . . | 0·15 p.ct. (L) | Fenner |
| to $\beta_1$ tridymite . . | 0·30 ,, (L) | Spotts McDowell |
| $\beta_1$ tridymite . } to $\beta_2$ tridymite . } | not accurately ascertained but comparatively small. | |

Among the indications of this table, it is noted that B and C contain high percentages of tridymite, while A and I show a preponderance of cristobalite—facts which have been further emphasized by micro-examination.

In the majority of cases such conclusions are well warranted. There are instances, however, when other factors militate against such uncompromising inferences. One of the most important is associated with the matrix, and the solution in this of quartzite particles, which, when so dissolved, possess the properties of amorphous silica. Thus, Wood, Houldsworth, and Cobb[9], who have investigated the influence of other matrix-forming substances on the properties of silica brick, state that the densities of fired quartz

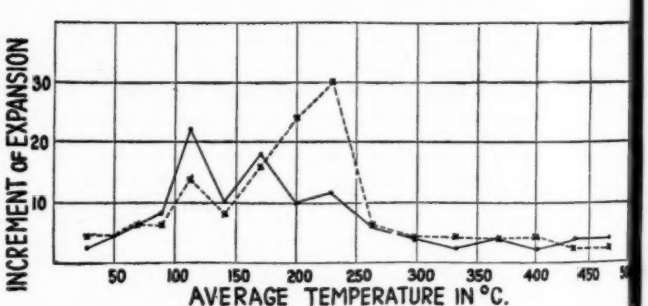


**Fig. 3.—Showing the Amount of Thermal Expansion at Specific Intervals of Temperature for Two Silica Products. The dotted line refers to material A and the continuous one to material B.**

mixtures made with 2 p.ct. of lime and 5 p.ct. of boric oxide are not widely different, but that very wide differences in the reversible thermal expansions of test pieces made from these mixtures were observed. In other words, a greater definition of the matrix of silica bricks is essential before the results of expansion data can give unqualified conclusions respecting the constitution.

### *The Siliceous Firebrick.*

This term may refer to a product made from a fireclay reinforced by quartzite particles of controlled size, or to one made from a pocket sand, found mainly in isolated pits in the carboniferous limestone of Derbyshire. This sand is comparatively very pure, containing upwards of 93 p.ct. of silica, and is associated with a white siliceous clay containing upwards of 75 p.ct. of silica. By blending the sands and the clayey matter, a mixture containing 91 p.ct. of $SiO_2$ and an average of 10 p.ct. "theoretical" clay matter is obtained. On firing, this product "matures" in the neighbourhood of 1420° C., forming a comparatively rigid matrix, in which some silica has been dissolved and has afterwards been precipitated as cristobalite. Thus, such products contain in the main

TABLE VII.

| Nature of Expansion. | Surface Temperature Range. | Relative Expansions for Products— | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | A. | B. | C. | E. | F. | G. | H. | I. |
| Tridymite . . . . . | 100° to 184° | 38 | 50 | 40 | 30 | 32 | 8 | 6 | 32 |
| Cristobalite . . . . . | 184° to 279° | 60 | 28 | 26 | 40 | 36 | 10 | 42 | 50 |
| Total expansion for experiment . . . | 15° to 490° | 140 | 118 | 108 | 112 | 106 | 38 | 118 | 122 |

unaltered quartzitic particles, together with a small amount of finely divided cristobalite in a well-developed clayey matrix. This brick is probably the best type of quartzitic refractory.

### THE DISINTEGRATION, CORROSION, AND EROSION OF SILICA FIRECLAY PRODUCTS WITH PARTICULAR REFERENCE TO CARBONIZING CONDITIONS.

#### *Introductory.*

The durability of refractories in the circumstances of their special uses is often limited by the influence of slags, slag-forming substances, and impregnations which they encounter. In fact, owing to the lack of understanding of the reactions involved in the phenomena of corrosion, erosion, and disintegration, it is becoming increasingly difficult to specify products which will withstand certain industrial conditions without possible failure "Iron" in its varied states in conjunction with carbon, the carbon gases, and certain other gaseous or volatile substances, is at the root of many observed cases of reduced life. The analyses of the reactions, however, is rendered exceptionally difficult by the existence of temperature variations and catalyzing influences.

#### *Some General Factors Involved in the Study of Corrosion.*

Scott[10], who gives an analysis of the corrosion of refractories, shows that, in the main two factors are conspicuously concerned. The first depends on the surface reactions which occur between the corrosive agent—slag or dust—and the material of the refractory. The second is concerned with the penetration of the refractory by such agents and the physical disintegration which follows such penetration; the former invariably accompanying the latter.

Chemical reaction takes place between "basic" and "acidic" materials in a very rapid manner; and thus lime or ferrous oxide will quickly react with silica, forming a fusible silicate. Further, where an amphoteric oxide of the nature of alumina or ferric oxide is present, reaction often occurs resulting in the formation of "spinels." Thus, both silica and fireclay materials must be prone to these actions in industrial use, where oxides carried as dust or slag are in contact with the refractory. The solution of the refractory by the slag at the area of contact can proceed to saturation at a definite temperature, with the result that diffusion must take place before further solution can occur. If the slag is highly viscous, this diffusion is hampered, with the result that the effect is merely superficial. The fluidity of the slag, then, is of the utmost importance in determining corrosive action. This factor depends on temperature and constitution. While in certain circumstances further solution may reduce the viscosity owing to such phenomena as eutectic formations, in other cases the viscosity is increased. Thus the constitutional factor is interdependent with viscosity. With increase of temperature, the viscosity is usually decreased, with the consequent increase in the activity of the slag.

The penetration of the slag can take place either by way of the pores or through the solution of the matrix. In estimating the influence of porosity in this respect, both the size and the disposition of the pores must be taken into account. A measure of the penetrability by a method such as is suggested by Ketchum, Westman, and Hursh[11] is a much more helpful criterion than one concerning the percentage porosity. According to Scott, "in this type of corrosion the corroding material penetrates certain pores, or, it may be, cracks or 'crizzles' on the surface of the refractory and works its way into the brick. Ultimately particles of the latter become surrounded by the corroding medium and tend to float into slag, or become detached, as the case may be. In fireclay refractories, for example, grog particles may be detached in this way. In many instances cracks on the surface of the brick are responsible for the commencement of the penetration, especially where the corroding agent is molten slag, as this latter is able to work its way by a crack where it could not, by reason of its relatively high viscosity, otherwise penetrate the ordinary pore. A tendency towards spalling will increase the amount of corrosion, as the cracks formed during spalling will serve as the *loci* for the penetration of the corrodant."

It has been abundantly proved that the matrix of a silica brick possesses very appreciable fluidity at the high temperature of its use, and tends to diffuse to cooler positions. This phenomenon helps considerably the passage of corroding agent such as iron compounds. How far the fluidity of the vitrified portion of a firebrick helps in the passage of corrodants is a moot point, but the possibility cannot be lost sight of in the study of corrosion.

The study of the physical chemistry and petrography of slags is still undeveloped. There can be no doubt that corrosion problems will stand a greater chance of solution when this subject advances. The existence of ferrous orthosilicate, $Fe_2SiO_4$, known as fayalite, has been established. However, Scott and others assert that the metasilicate does not solidify from an appropriate melt, but a mixture of tridymite and fayalite is obtained. Complex metasilicates of iron magnesium and calcium, however, may be formed when slag-forming constituents containing lime and magnesia are present. Under oxidizing conditions there is no reaction between ferric or ferroso-ferric oxide and silica, and no ferric silicate has been identified. Thus, magnetite, fayalite, and free silica in the tridymitic form seem to be the crystalline compounds likely to be indicated in the petrological examination of purely ferruginous slags.

#### *Some Factors in the Study of Spalling and Disintegration.*

Strains set up in a refractory structure during usage, with consequent weakening and sometimes final disintegration, may be caused by a number of circumstances, chiefly including (*a*) temperature variations, (*b*) alterations in the nature and constitution of the refractory, (*c*) the deposition, sometimes followed by crystallization or solidification of foreign substances in the pores, and (*d*) a combination of the above causes.

The nature of the first-mentioned category is circumscribed by a study of spalling, which may be described as the failure of a refractory to withstand without disruption those stresses induced by temperature fluctuations or thermal shock under the general or special conditions of industrial usage. In the theoretical conception of spalling, at least three factors are involved. These are (1) the rate of change of temperature, which can be effected under definite conditions in the refractory mass; (2) the elastic and viscous properties of the material; (3) the nature and extent of the volume changes set up by rapid fluctuations of external temperature. The first is defined by the coefficient of temperature diffusivity of the material, together with measurements respecting the size and contour of the mass. The second is exceedingly difficult of definition, while the third can be adequately circumscribed by a study of the thermal expansion and velocity of these changes.

Norton[12] has recently evolved a formula based on considerations of homogeneity which gives a value for spalling tendency. It is similar to the well-known formula of Winklemann and Schott for the endurance of glass, and may be written:

$$S = \frac{E}{F.K^{\frac{1}{2}}}$$

where S = spalling tendency, E = coefficient of thermal expansion, F = maximum shearing strain, K = the coefficient of temperature diffusivity. The maximum shearing strain or "ultimate strength" factor is not in itself truly elementary, but is rather a function of elasticity, viscosity, and a "heterogeneity" factor—the last-mentioned including the extent and nature of vitrification and porosity. Fig. 4 shows empirically the relationship between degree of vitrification and porosity, mechanical strength, and resistance to spalling of fireclay products containing no free silica.

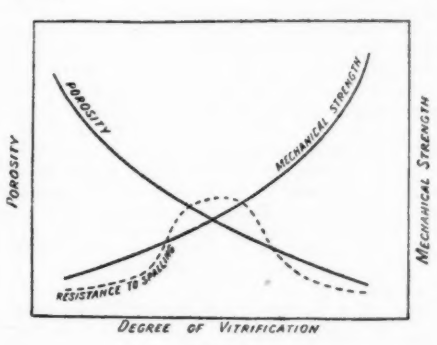


Fig. 4.

In testing the efficacy of his formula, Norton showed that the diffusivity factor has little significance in the comparison of the spalling tendencies of different fireclay products; its influence being completely outweighed by that of the other factors. The coefficient

of thermal expansion for firebricks shows considerable variation for different products. In illustration, Norton obtained values varying from 50 × $10^{-7}$ to 133 × $10^{-7}$ in C.G.S. units for the average value of this constant at 500° (15° and 1000°) while Booze and Phelps[12] obtained even greater variations. This fact is of the highest importance, and may account for many of the structural weaknesses, noted in high-temperature installations, for which there is otherwise no explanation. This variation appears to be connected with two variables—viz., the amount of firing and the constitution of the original clay. It is now an established fact that products high in alumina have, in general, low coefficients of expansion, while those high in silica have high values for this property. In some instances continued firing seems to increase the thermal expansion, in others to decrease it. It has been stated that the lowest value for the coefficient of thermal expansion was obtained with a test piece which had been fired to an extremely high temperature. The firing treatment in all probability produced an excessive amount of vitrified or glassy matrix which, as such, possesses a comparatively low value for the constant in question. Thus, it is probable that bricks heated drastically enough to cause all the "free" silica to go into solution in the matrix will show low expansion. Thus the spalling tendency of such a material will be due to the "glassy" structure, and not to the presence of "free" silica. High expansion in fireclay refractories may be considered to depend on the nature and quantity of the silica present. The free silica, which is originally present as quartz, is, by continued heating at high temperatures, converted into cristobalite, with a consequent big increase in the average thermal expansion and spalling tendency of the product. This is well illustrated by Steger[14], who investigated the behaviour of a clay containing 73 p.ct. of $SiO_2$ and 17 p.ct. of $Al_2O_3$ after repeated firings. Table VIII. shows the expansion data determined on this material after different heat-treatments.

TABLE VIII.

| Firing Treatment. Burned at | Thermal Expansion in C.G.S. Units for the Temperature Ranges. | | | |
|---|---|---|---|---|
| | 15° to 300°. | 300° to 500°. | 500° to 600°. | 600° to 750°. |
| 900° C. . | 60 × $10^{-7}$ | 95 × $10^{-7}$ | 242 × $10^{-7}$ | 18 × $10^{-7}$ |
| 1250° C. . | 160 ,, | 110 ,, | 230 ,, | 35 × ,, |
| 1450° C. . | 322 ,, | 52 ,, | 55 ,, | 45 ,, |

A study of this table shows that the reversible thermal expansion due to cristobalite, and taking place at 210°, has been increased at the expense of that due to quartz, and taking place at 575°, by increased heat treatment. In other words, the quartz has been converted to cristobalite, with a consequent increase in the spalling tendency of the product at low temperatures. Further, the actual conversion itself, because it is attended by a permanent expansion, can set up strains in the product, causing local weakness, which predisposes the material to spalling. It would seem, then, that bricks made from siliceous clays are liable to spalling much more so than the more aluminous products. The fact that the latter material often shows conspicuous permanent contraction as compared with the siliceous clay product counteracts some of its advantages in industrial usage.

In the study of the constitution of silica products, it has been shown that these bricks are liable to show exceptionally large expansions at specific temperatures, due to the inversional changes of the $\alpha$-$\beta$ forms of either tridymite (110° and 160°), cristobalite (210°), or quartz (575°). The cristobalite change is by far the most dangerous from the spalling point of view. In a laboratory investigation of these low-temperature changes, the cooling of 2½-in. cubes of seven different varieties of straight silica bricks from 450° in air was sufficiently drastic to crack or shatter every piece. Samples containing high proportions of cristobalite were easily cracked by temperature fluctuations in the neighbourhood of 200° C.; while, though much more resistant in this respect, tridymite bricks could be cracked by rapid variations in temperatures between 100° and 200°. In those modern carbonizing installations where only highly converted silica products are used, it is absolutely necessary that the rate of rise of temperature up to 700° to 800° be very carefully controlled, otherwise disruptive action will take place in the wall. The precise mechanism of the spalling of silica bricks is hardly understood. Much must depend on the size and disposition of quartz, cristobalite, and tridymite crystals with respect to the matrix. It may be that there are a number of ways in which the brick may thus be cracked. For instance, the expansion thrust or release of the crystalline silica may crack the brittle matrix; or again, the crystals themselves may split. There is some evidence that both features occur; the more important from the spalling viewpoint being the cracking of the matrix.

Most silica products as supplied to industry undergo some permanent expansion during high-temperature usage. This, of course, is due to conversion of residual silica to lower specific gravity forms. Naturally, in manufacture, there is every endeavour to reduce this factor to a minimum; but unless the greater care is taken of it, and allowances are made for it, definite strains will be set up in the structure, with consequent liability to disintegration. It must always be borne in mind that in most phases of carbonizing there are appreciable temperature gradients existing in refractory structures during use; and any conversional changes will be necessarily unevenly developed, thus increasing the involved strains.

Besides alteration in the crystalline constituents, continued usage at high temperatures must influence the nature of the amorphous substance or matrix. With such heat treatment it becomes definitely more of a homogeneous glass, possessing continuity and therefore more liable to the influences of embrittling agencies. There are few or no data defining this alteration, but the examination of retort settings after service confirms the existence of this phenomenon.

Finally, foreign substances other than corrodants find their way into the pores of a refractory. This penetration may be in the gaseous form, with the subsequent deposition and, in some instances, crystallization of a solid. Such impregnations often give rise to severe and highly localized strains in the interior of the mass, forming a multitude of minute cracks which eventually knit-up, giving rise to local or surface disintegration. This disease is often masked by other attendant operational influences which themselves accentuate failure. Nevertheless, it is often the first circumstance in the ultimate failure of a refractory.

### *Carbonizing Conditions and Their Influence.*

In a general manner, the study of carbonizing conditions in relation to the durability of refractories can be resolved into a consideration of the influence of (1) temperature variations (*i.e.*, spalling), (2) constitutional changes in the refractory or some of its constituents, (3) coal and coke in contact with the refractory wall, (4) deposited ash, (5) the burning gases in the combustion chamber, and (6) local circumstances, including features of the design and erection of the installation.

As introductory to a consideration of the influence of coal or coke in contact with the refractory wall, perhaps the results of an examination, made by the author [15], of a semi-silica product, which had been in use in a coke oven wall for eighteen years, will be of some interest and value. A section through the wall from the coking chamber to the flue side showed a defined "layering" effect. The end forming the coking chamber boundary was slagged on the surface, giving the appearance of an incrustation, and its red colour persisted to a depth of about 0·5 cm. Following this layer, and having a thickness varying from 3 to 4 cm., a "carbonated" layer showed itself. This layer was completely blackened with an impregnation of carbonaceous matter. A "loss-on-ignition" determination indicated the presence of 1·34 p.ct. of carbonaceous matter. The layer succeeding this carbonaceous portion was invariably white (the original brick was reddish), and varied in thickness from 3 to 6 cm.; this thickness apparently depending on the position of the material in the coke-oven wall. This layer either continued for some distance through the wall or gave place to an alternation of layers of different shades of yellowish-red. Finally, the surface on the combustion chamber side was vitrified, and had obviously been subjected to the influence of dusts at high temperatures. The effect, however, was only superficial. It is interesting to note that the composition of the surface material (coking side) was somewhat different from the normal product, there being less silica and more alkali and iron oxide in this portion. The occurrence of the carbonated portion at approximately a centimetre from the coking surface is worthy of emphasis. Evidence points to the conclusion that the presence of this carbonaceous matter was due to the penetration of gaseous distillation products of coal which were subsequently decomposed, with the secondary deposition of carbon. The effect of re-

ducing gases is well shown in the white layer following the carbonated portion. Further, this layer and the carbonated portion had been rendered very friable and mechanically weak by this usage. In other words, the penetrations had obviously weakened the matrix of the product. These features of coke oven walls are often noted; and this description therefore gives an impression of a few of the many changes taking place in or on the refractory material.

*The Influence of Iron Compounds Mainly on the Coking Side.*

In the gas retort and the coke oven, " iron " can and does pass from the coking coal to the brickwork. There is evidence which suggests that the mechanism of this passage is associated with the formation of a complex gaseous compound which is decomposed on the surface or in the pores of the brickwork. Some suggest that in certain carbonizing operations iron carbonyl is formed. While this is not refuted, the present author is of the opinion that steam plays a considerable part in both the transfer and the subsequent influence of the iron. Much evidence of the existence of newly-deposited hæmatite is to be found in certain zones of a vertical retort, suggesting a series of reactions in the coke and then the brickwork, with the final crystallization of the mineral. How far this impregnation causes surface weakening is a point worthy of solution. It is pertinent here to note that Rees[16] traced a case of " spalling " in a silica horizontal retort to the disintegrating influence of an impregnation. An investigation of certain " blackened " patches showed the existence of iron oxide together with a deposition of carbon. Rees concluded that the presence of iron oxide facilitated the decomposition of carbon monoxide with the deposition of carbon and the consequent weakening of the structure.

During " scurfing " or the elimination of the incrustation encountered in the carbonizing industries, portions of the refractory are sometimes dislodged from the retort. Though a number of explanations may be put forward to account for this trouble, it may be that the depositions on and in the wall have had a weakening effect, probably at definite planes, which predisposes the material to failure during this operation. In any case, where the " scurf " is burned off by the admission of air, localized high temperature, owing to rapid combustion, may take place; and this, besides embrittling, may easily disintegrate an already-weakened material.

Depending on the temperature and nature of the atmosphere, the " iron " exerts either a surface disintegrating action or a corrosive influence. Where the temperature is sufficiently high, fusible silicates will be formed, which, depending on temperature gradient, porosity, and nature of the matrix, among other factors, will tend to diffuse into the brickwork, probably causing ultimate failure. The nature of the atmosphere is of great importance—a fact well illustrated by the work of Vickers[17]. This investigator has shown that the influence of steam in reducing the refractoriness of a cone containing added ferric oxide is very pronounced; the reduction being of the order of 200° C., from 1400° to 1200°. Further, such an atmosphere may reduce considerably the temperature of formation of fusible iron silicates, with the attendant increase in the fluidity of such a slagging agent at the temperature of action. The atmosphere in gas retorts and coke ovens is complex and variable; and such influences may be anticipated. Further, the gases often take selective paths by way of the wall in vertical retort work—a fact which must accentuate the action of the atmosphere at the surface. Where " steaming " is adopted, there certainly seem to be conditions such as will render the formation of fusible iron silicates comparatively easy. Erosion of retort work can take place by the rubbing action of coke on the more or less fluid surface—a circumstance which may lead to ultimate failure of the retort.

The value of the refractoriness-under-load of a firebrick impregnated with ferruginous slag is very considerably reduced. In the case of silica products, however, many observers have noted that up to a certain degree the absorption of slag or dust rich in " iron " at high temperatures affects the softening-point under load to a relatively small extent. Sieurin[18] states that the presence of iron estimated at 10 p.ct. of ferric oxide has only a very small effect on the under-load value. Iron compounds impregnating a silica product may have attacked or combined with the matrix; but the interlacing skeleton of silica, mainly in the form of tridymite and cristobalite, may be unaffected. In these circumstances, the product appears to possess definite structural stability. The present author has noted that an under-load test of 30 lbs. per sq. in. on a pocket-sand silica brick (92 p.ct. $SiO_2$, 4·5 p.ct. $Al_2O_3$ in its original state) impregnated with ferruginous matter and containing an average of 8 p.ct. of iron oxide (estimated as ferric oxide) indicated the squeezing out of a very fusible iron slag in the neighbourhood of 1050°, but the test piece maintained its structural stability to a conspicuously high temperature. It would seem that until that condition has been reached, when the bulk of the silica has passed into solution, the refractory will maintain some structural stability.

*The Influence of Salty Coals.*

Coals used in the carbonizing industries contain sodium chloride in varying amounts from a mere trace to approximately 0·5 p.ct. When the coke has reached a temperature of 800° to 900°, the salt is volatilized, and, mixing with the gas in the retort or oven, is decomposed with the formation of soda and hydrochloric acid. The soda fumes penetrate the brickwork and give rise to a series of reactions which are detrimental to the brickwork. Cobb[19] has shown that soda, alumina, and silica can react together at 1000° C. (but not at 800°) with the formation of very fusible sodium aluminium silicate. Ferric chloride, which may be present in salty coal, probably helps in the fluxing action by its reduction to ferrous chloride. Steam being essential to this reaction, the drying of coal may probably reduce the trouble. Silica materials appear to be highly resistant to salt corrosion. He also states[20] that when sodium chloride is volatilized at 800°, it is hydrolyzed by steam as follows: $2NaCl+H_2O+CO_2=Na_2CO_3+2HCl$. The hydrochloric acid formed reacts with the pyrites in the coal to produce ferrous chloride, and with ammonia to form ammonium chloride; the final result being the formation of the following corroding agents: Sodium chloride, sodium carbonate, ferrous chloride, and ammonium chloride. These penetrate the brickwork, and, reacting with its constituents, may bring about its failure.

Clews and Thompson[21] state that when silica and sodium chloride are strongly heated in dry air, sodium silicate and chlorine are formed; in moist air, sodium silicate, hydrochloric acid, and a smaller quantity of chlorine; while in moist nitrogen, sodium silicate and hydrochloric acid result. The lower limit of the reaction is 600° C., and the extent of the reaction is very small at 1000° C. Thompson[22], Rees[23], Wilson[24], and Lindley[25] have studied the resistance of silica bricks to the fumes of alkali and ammonium chlorides, when salty coals are employed in coke ovens. According to Gardner[26], silica bricks are capable of absorbing alkali fumes over very considerable periods of time without disintegration or loss of mechanical strength. This author has noted, however, that both silica and siliceous products are attacked in time.

At high working temperatures, an intermittent erosion, due to the detachment of a thin shaving of the face of the retort with the carbon at each scurfing period, may take place. It is probable that this thin glassy surface layer detaches itself from the brick owing to fluctuations in the temperature at the retort face during scurfing. Under moderate temperature conditions, the alkali fumes appear to penetrate to a greater depth beneath the surface before reaching a temperature sufficiently high to form a vitreous layer of silicate. Consequently, disintegration may take the form of flaking-off of an irregular layer, 0·5 to 0·75 in. thick, at intervals of 12 to 18 months.

Gardner reports an investigation of the failure of some retorts which had become unworkable due to roughness as the result of irregular erosion brought about by the use of salty coals. Analysis of the glassy surface layer revealed the fact that the alkali content had increased from 0·54 in the original brick to 3·8 p.ct., and the iron oxide ($Fe_2O_3$) from 1·50 to 2·8 p.ct. The salt content of the coal in use was approximately 0·3 p.ct.

In the case of fireclay material worked at low temperatures, alkali fumes cause the surface to become badly crazed after several years' working; but until disintegration takes place, the changing seldom causes any difficulties with the working of the retorts.

*Other Features.*

It is not possible in the space available to deal with other features of the failure of refractories in the carbonizing industries. Many such do not have a general significance, but can be traced to local features of design and manipulation of plant. It is, of course, difficult to draw a line between the features of general significance and those which can be classed as particular, for many of the latter category contain aspects of fundamental importance. Perhaps the effects of

(1) ash accretions or (2) the volume changes of the charge taking place during coking with certain types and mixtures of coal, or (3) local "hot spots" may be placed in this category, since alterations in the design and working of plants may prevent their detrimental influences.

The predisposition of the jointing cement to start failure has often been the subject of comment. In fact, the jointing cement has sometimes taken the blame for the failure of the refractory itself. This cement must be uniform in mixture, finely ground, and must possess a certain plasticity. This means that in all silica mortars a certain clay content is necessary. According to some observers, it is this clay content which serves to start failure by the attack of slag-forming substances. It would appear that if the cement is capable of forming and maintaining the whole retort as a monolithic structure under working conditions, the results, as far as the cement is concerned, will be very desirable. If, however, it contracts in its vitrification, leaving fissures and the like, the structure is predisposed to failure. To specify a cement to give ideal conditions is certainly difficult.

## THE TECHNICAL CONCEPTION OF THE STRUCTURAL STABILITY OF SILICA AND FIRECLAY PRODUCTS.

### *Refractoriness.*

Refractoriness implies the resistance to softening under the effects of excessive heat treatments. It has been clearly recognized for some considerable time that the softening of clay and such like materials at elevated temperatures is not a specific property analogous to true melting, but involves both time and temperature factors. This recognition is of the utmost importance in emphasizing the arbitrary nature of the conception of refractoriness.

In the actual determinations of the refractoriness, as at present carried out, a definite size of cone (2 in. in height and ¾ in. side for the triangular base), ground to the same shape as a Seger Cone, is used as the test piece. This is cemented into a slab (usually bauxitic) and surrounded by suitable Seger Cones. It is placed in a furnace, the temperature of which is raised by 10° C. per minute. The result is adjudicated either on the squatting of the test piece or its condition when a specific Seger Cone bends. Thus some investigators observe the Seger Cone which is bending as the material bends, and take this as an indication of the "squatting temperature" or refractoriness. Others observe "signs of fusion" at a specific point in the heat treatment. Such signs adopted are: (1) Angular edges of the material beginning to lose their angularity, (2) piece showing signs of bending, and (3) matrix showing signs of running out. Though there are decided discrepancies between the two types of observations, either the one or the other gives some criterion of the value of a refractory material.

The mechanism of the squatting or bending of a cone is interesting, and of considerable importance in formulating the value of the refractoriness test. Knead and Jefferson[27] consider the phenomenon in the following manner:—"When heated with the base in a horizontal position—*i.e.*, with one edge vertical—the cone is subjected to two forces tending towards deformation—viz., its own weight and its surface tension. These forces are resisted first by cohesion, and, as this decreases with rise in temperature, by internal friction or viscosity. It is evident that the weight or load is greatest in the bottom layer under the apex; thus causing the cone to tilt and then progressively to bend over. A symmetrical cone with the apex over the centre of the base is more likely to squat on itself, and not to bend like the Seger Cone, which has the apex over one corner of the base. With some materials the force of surface tension plays the major part in causing deformation—*e.g.*, Fieldner, Hall, and Field[28] have demonstrated that it is possible to heat cones of certain coal ashes in a horizontal position supported only at the base, and even under these extreme conditions the material collects in the form of a blob before it has had time to bend under its own weight." These observations indicate that squatting is, in some cases—notably with certain Scottish clays—very rapid, while in others—notably certain Stourbridge clays—it is a comparatively protracted affair; thus illustrating the limitations in the effective indications of the refractoriness test. The refractoriness of a good fireclay or its product, under normal conditions of test, varies from Cone 20 to Cone 35 (1530° to 1770° C.), while that of a silica product varies from Cone 32 to Cone 34 (1710° to 1750° C.), and a siliceous product about Cone 30 to Cone 32 (1670° to 1710° C.). Such data form a preliminary guide to the heat-resisting properties of refractories.

### *Refractoriness-Under-Load.*

The refractoriness test, though useful, gives no indication of the conjoint influence of pressure and temperature—a state of affairs more often encountered in industrial usage than the effect of fusibility *per se*. It is highly desirable to have data indicating the mechanical stability of a refractory at high temperatures. The study of the refractoriness-under-load has proceeded for the past twenty years; but the early work of Mellor laid the basis of the present accepted test. Dale[29] has developed this test to a high degree of proficiency, recently obtaining data of fundamental significance.

The original test consisted in heating a test piece 3½ in. by 2 in. cross-section under a definite load—usually 50 lbs. per sq. in.—at a rate of rise of temperature of 10° C. per minute in an electric furnace. The cone-temperature of collapse—*i.e.*, as indicated by a definite amount of squatting or deformation of the test piece—was taken as an indication of the refractoriness-under-load. If the Gas Engineers' classification of silica and fireclay materials be accepted (silica products greater than 92 p.ct. $SiO_2$, fireclay less than 82 p.ct., and siliceous 82 to 92 p.ct. $SiO_2$) it is found that silica, siliceous, and fireclay products have approximate refractoriness values of 1720°, 1680°, and 1650° C. respectively, as indicated by the cone-temperature method. Under a load of 50 lbs. per sq. in., however, the temperatures of collapse of these three products are approximately 1670°, 1480° to 1600°, and 1350° C. respectively. Variations from these figures depend on a number of factors, including (1) the composition of the refractory materials (*i.e.*, the amount of fluxes and iron oxide), (2) the firing treatment, (3) the physical nature (*i.e.*, the texture). The rigidity of the silica brick is maintained up to the point of collapse, which is approximately 300° higher than the "safe" value for an average fireclay product.

By means of a lever system, Dale[29] determines the movement of the test piece and carborundum supporting-rods during the test. Since the carborundum shows a linear expansion, any deviation of the expansion graph from a straight-line curve is a characteristic of the brick under investigation. The data so obtained have given valuable information concerning the probable behaviour of silica and fireclay refractories in practice, and have elucidated a number of important practical points. The following is a brief résumé of some of the conclusions drawn from this work:

(1) With a commercial silica brick of sp.gr. 2·350 containing some unconverted quartz located as nuclei in the larger rock fragments, under a load of 75 lbs. per sq. in. failure began at 1500° and total collapse ensued at 1570°, owing to mechanical stress. Under a load of 4 lbs. per sq. in., the brick stood up until squatting resulted from softening of the matrix.

(2) Bricks containing appreciable quantities of unconverted quartz are liable to disruption under high external loads at comparatively low temperatures unless an especially elastic matrix is present.

(3) A silica brick containing a little quartz but with an exceptionally rigid bond did not begin to show subsidence until 1670°, and the total collapse did not take place until 1710° to 1730° was reached.

(4) With commercial silica bricks containing a large percentage of cristobalite, under a load of 4 lbs. per sq. in., the highest temperature obtainable in the load test furnace was reached without showing any abnormal expansion at high temperature. Under a load of 50 lbs. per sq. in. appreciable deformation did not begin until 1700°; and the brick failed between this temperature and 1730°. A rapid expansion occurred between 200° and 350°, but this was much less under the greater load. This suggests that cristobalitic material is highly resistant to loads at very high temperatures.

(5) In the case of a commercial brick with a good tridymitic development, failure under high loads may occur below 1600°, but if the matrix possesses moderate viscosity the brick may withstand much higher temperatures. No particularly marked rapid expansion takes place at low temperatures.

In general, silica bricks show a mechanical fracture in contrast to a squatting or viscous deformation which is the usual mode of failure of fireclay products.

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Fig. 6, due to Dale, shows the general mechanism of subsidence for firebricks. The consideration of data collected shows that attention should be directed to the range A B. Below a temperature approximating to A (the point at which marked flattening of the curve becomes noticeable), deformation under loads occurring in actual practice will be small. Within the range 1200° to 1350°, deformation both in rate and in quantity is governed by the actual temperatures and

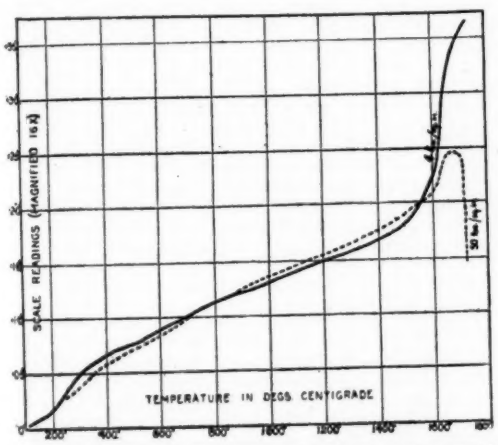


**Fig. 5.—Showing the "Under-Load" behaviour of a certain Superior Straight Silica Product under loads of 4 lbs. and 50 lbs. per sq. in.**

load values. In certain cases, this deformation may be excessive. Above a temperature corresponding with the point B, excessive deformation can occur under low loads. Thus for fireclay goods the determination of the subsidence curve gives a valuable clue to the likely behaviour in the circumstances of their industrial usage. Further, it shows that the temperature of complete squatting is not a safe criterion of the industrial efficiency of these products.

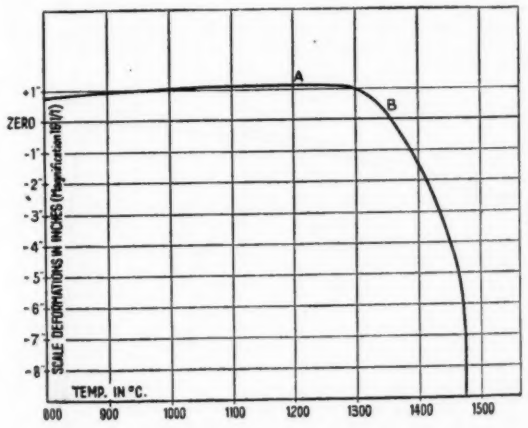


**Fig. 6.**

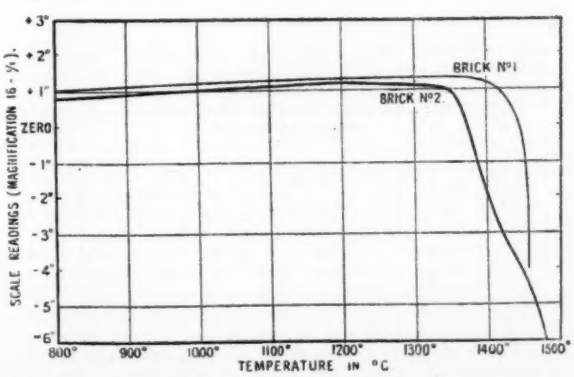


**Fig. 7.—Showing the "Under-Load" behaviour of Two Fireclay Products.**

The influence of grog should also be considered. There appears to be a limit to the amount of grog which can be incorporated in a fireclay brick; and information regarding the limit can be deduced from the modified under-load test. When non-porous or excessively vitrified grog is used, failure is mostly by rupture. With a moderately porous grog, a pre-soaking of the grog particles in water leads to increased resistance to deformation at temperatures below that of rapid collapse. With 40 p.ct. or more of vitrified grog, large particle size tends to cause premature failure under stress at high temperatures, chiefly by rupture round the large grog particles.

Investigation on the "pocket-sand" silica product (92 p.ct. $SiO_2$) illustrates the influence of matrix development on the under-load test in a very effective manner. Figs. 8 and 9 show the refractoriness-under-load curves for two siliceous bricks—one which has

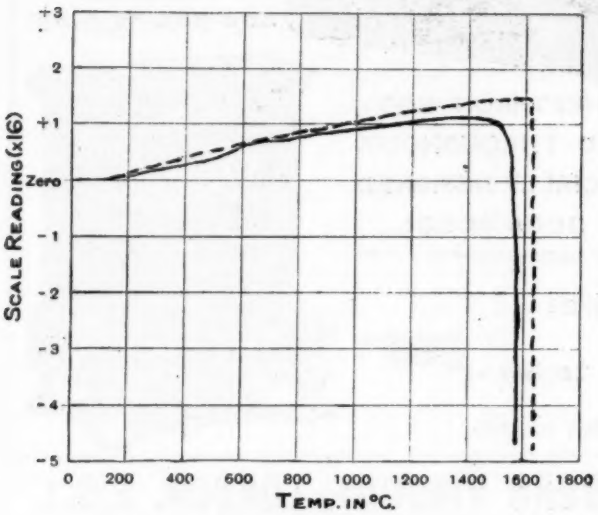


**Fig. 8.—Showing "Under-Load" behaviour of "Pocket-Sand" Siliceous Products under a load of 50 lbs. per sq. in. The dotted line refers to a well-fired product with a well-developed matrix; the continuous line to one which has received an ineffective firing.**

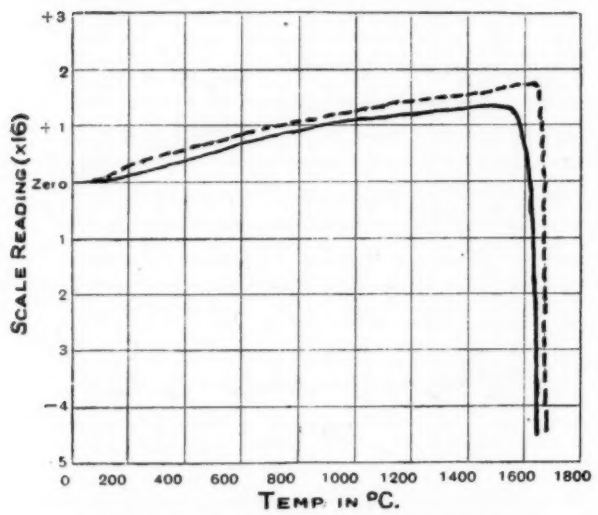


**Fig. 9.—Showing the "Under-Load" behaviour of "Pocket-Sand" Siliceous Products under a load of 4 lbs. per sq. in. The dotted line refers to a well-fired product with a well-developed matrix; the continuous line to one which has received an ineffective firing.**

received an effective firing, the other an ineffective one. In the case of "soft" burned, at 50 lbs. per sq. in., failure begins at about 1360°, whereas the "hard" burned product shows no failure until a temperature of approximately 1600° is reached. Further, these curves show in the case of the hard burned the presence of cristobalite, which is absent in the soft burned. This fact is indicated by the irregularity in the curve in the neighbourhood of 200° C. It is interesting, here, to remark that there is not a conspicuous difference in the temperature which produces an effective maturing, and that which produces the soft-burned product; the material quickly developing a matrix in the neighbourhood of 1400°.

### *After-Contraction and After-Expansion.*

Those changes which occur during the firing of refractory materials belong to a class known as arrested reaction. In these the chemical and physical changes are arrested at particular and definite stages before they are completed. As previously indicated, when firebricks are burned or fired in the kiln, the fluxes melt and dissolve the less fusible materials, binding the whole more or less firmly together. A certain amount of contraction occurs during the operation, and if not completed during the firing of the brick, it will subsequently continue when the brick is in use. This is called the after-contraction. If this after-contraction is considerable, the masonry of the furnace will most certainly be displaced when the bricks are in use. The after-contraction must be small—certainly under 1 p.ct.

Straight silica products usually show an after-expansion consequent on the more or less gradual change of quartzitic silica with a specific gravity of 2·65 to one or both of two other varieties with specific gravities 2·28 and 2·32. The complete change involves considerable expansion, but it is a fairly slow reaction. It can be seen, therefore, that the original firing of silica bricks should result in such a reduction in specific gravity as is compatible with the subsequent use of the product. For coke-oven and gas retort work where an after-expansion would set up very bad strains in the structure, the after-expansion effect must be as low as possible, and thus the specific gravity of such material must be low, for, as Rees has shown, with most lime-bonded silica bricks except the very coarse-grained products there is a linear relationship between specific gravity and after-expansion as obtained by test.

In the case of semi-silica or highly siliceous products, the tendency is to obtain a product which does not show either after-expansion or after-contraction. This may or may not be obtained where silica rock is added to a fireclay as a reinforcement, much depending on the grain size of the addition. In the case of a pocket-sand silica product, however, such an approximation to a volume constancy, except, of course, for the normal thermal expansion, is obtained. Such a product containing approximately 10 p.ct. of clay substance and a very small quantity of micaceous and calcareous matters, together with about 80 to 85 p.ct. free silica, is in large use in the gas industry of the day. When the matrix of this product is well developed, the structural properties, as far as the carbonizing industries are concerned, are of a high order.

## THERMAL PROPERTIES.

The heating efficiency of many high-temperature processes cannot be computed without quantitative data on the fundamental thermal properties of refractory products. Again, improvement in the technique of many industries has made it apparent that refractories must be divided, according to the uses for which they are intended, into two groups—namely, heat conductors and heat insulators. In the walls of gas retorts and coke ovens, high thermal conductivity is desirable, since the more rapidly heat is transferred through the wall, the more easily is the desired temperature attained on the carbonizing face. Consequently a definite quantitative knowledge of the specific heat, heat capacity, thermal conductivity, diffusivity, and surface emissivity of refractories becomes a vital necessity. Many of these properties remain at present practically uninvestigated.

### *Specific Heat.*

Bradshaw and Emery[30] have calculated that it requires 94 lbs. of coal of calorific value 8100 calories per lb. to raise the temperature of one ton of firebrick from ordinary temperatures to 1200° C. Also, Green[31] has shown that, to raise the temperature of a kiln containing 100,000 bricks in its construction to an average temperature of 500°, a minimum of seven tons of coal is necessary.

The specific heats of refractories vary with temperature. For fireclay products, Wilson, Holdcroft, and Mellor[32] showed that the relationship

$$S = 0{\cdot}193 + 0{\cdot}00006t$$

circumscribes the data for the *mean* specific heat between 0° C. and $t$° C. up to a temperature of 1300°. Bradshaw and Emery, using a similar method with additional elaborations, give

$$S = 0{\cdot}193 + 0{\cdot}000075t$$

as correct, where $t$ varies from 25° to 1400° C. for the

variation of specific heat (S) with temperature (*t*) between temperatures of 25° C. and 1400° C.

Apparently no relation between constitution and specific heat has been found to exist. It may be noted that little difference is found between the specific heats of fireclay and silica materials. Table IX. gives "utility" values based on the work of Bradshaw and Emery, and Heyn and co-workers[32].

TABLE IX.—*Specific Heats of Fireclay and Silica Products at Definite Temperatures.*

| Material. | Specific Heats at ° C. | | | | | | |
|---|---|---|---|---|---|---|---|
| | 200°. | 400°. | 600°. | 800°. | 1000°. | 1200°. | 1400°. |
| Firebrick . | 0·213 | 0·245 | 0·278 | 0·304 | 0·314 | 0·323 | 0·332 |
| Silica brick | 0·219 | 0·253 | 0·279 | 0·298 | 0·312 | 0·324 | 0·334 |

The work of Wietzel[34] does not show appreciable differences in the specific heats of quartz glass, cristobalite, quartz, and tridymite.

The heat capacity gives an idea of the relative amounts of heat absorbed by structures of different materials. The heat capacity per unit volume increases rapidly with temperature.

TABLE X.

| Temperature. | Heat Capacity per Unit Volume. | |
|---|---|---|
| | Firebrick. | Silica Brick. |
| 100° C. . . . . | 0·400 | 0·349 |
| 1000° C. . . . . | 0·570 | 0 495 |

It may be interesting here to consider the influence of firing treatment on the apparent specific gravity, and therefore on the heat capacities, of fireclay and silica products. The apparent specific gravity is related to the true specific gravity and percentage porosity according to the following formula:

$$Sa = St\left(1 - \frac{P}{100}\right)$$

where $Sa$ = apparent specific gravity.
$St$ = true specific gravity.
$P$ = true percentage porosity.

Thus, assuming that the porosity remains constant, the treatment which alters the true specific gravity will have an effect on the apparent specific gravity. In the "maturing" stage of the firing, the true specific gravity of silica products may fall from 2·65 to 2·30, particularly if the firing is prolonged in order to obtain the full effect. Consequently, with a silica product of normal porosity (25 to 30 p.ct.), this change may be expected to result in a change of apparent specific gravity from 1·95 to 1·60. While effecting this change, continued heat treatment tends to increase slightly the porosity of silica products. Though after a certain stage has been passed this latter change is small, yet its influence is also in the direction of a reduction of the apparent specific gravity. Thus it can categorically be asserted that superior silica products have comparatively low apparent specific gravities, and in consequence comparatively low heat capacities.

In general, the true specific gravity of a fireclay material is only slightly altered by continued heat treatment in the range of maturing temperatures. Usually this alteration is a decrease, which has been given some quantitative significance by the author. Thus the true specific gravity of a fireclay product may decrease from about 2·63 to 2·61, and maintain the shape and other desirable properties of a well-burned material. This alteration in true specific gravity has little effect on the apparent specific gravity. With increasing vitrification of a fireclay there is always a tendency towards, and in most cases there actually is, a decrease in porosity; the net results usually being an increase in apparent specific gravity. Thus, continued heat treatment in the vitrification range (up to a certain point) increases the apparent specific gravity of a fireclay, and a well-burned fireclay product has a relatively high apparent specific gravity ranging from 1·8 to 2·2. The heat capacity of fireclay products is therefore decidedly greater than that of silica products.

### *The Temperature Diffusivity and Thermal Conductivity of Fireclay and Silica Products.*

The temperature diffusivity may be broadly considered as that property which controls the velocity of propagation of temperature in a mass of refractory material. The coefficient of temperature diffusivity may be said to express in C.G.S. units the rise in temperature produced in one cubic centimetre of substance by one calorie in one second through one square centimetre of a layer one centimetre thick having a temperature difference of one degree Centigrade between its faces. This conception has a particular value in those systems in which temperature is of more significance than total heat—*i.e.*, in the coke oven and the gas retort. In fact, in considerations of the "carbonizing" face temperature, temperature diffusivity measurements are of great importance.

The reported values of the coefficients of temperature diffusivity and thermal conductivity seem to depend on the nature of the adopted methods. Consequently there is a wide variation in the data available. The methods of measuring the thermal conductivity of refractory materials which are based on Fourier's equation for linear diffusion essentially determine the co-efficient of temperature diffusivity. Using such a procedure, Heyn[35] gives 0·0032 at 1000° C., Green[36] 0·0040 at 1000°, and Tadokoro[37] 0·0142 at 900° C. for the temperature diffusivity of a silica brick. In those methods of determining the co-efficient of thermal conductivity which are essentially calorimetric, the temperature diffusivity can be computed from the observed values for thermal conductivity. This computation follows the equation $K = kcs$, where K = co-efficient of thermal conductivity, $k$ = the co-efficient of temperature diffusivity, and $cs$ = the heat capacity per unit volume. From the work of Dougall, Hodsman, and Cobb[38], the value for the temperature diffusivity of a firebrick at 500° is 0·0055, at 1000° 0·0068; and for a silica brick at 500° 0·0053, at 1000° 0·0088.

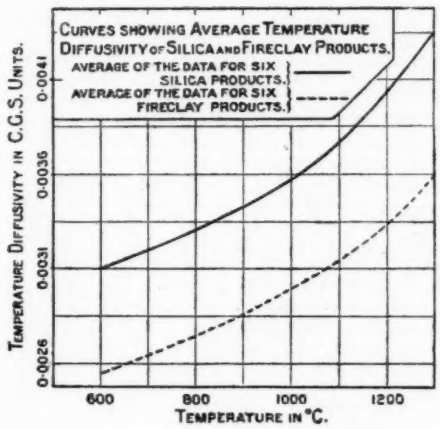


Fig. 10.

In considering the factors influencing temperature diffusivity the following points are of interest:

(1) The temperature diffusivities of fireclay and silica products increase with temperature.
(2) Increased firing treatment increases the value of this co-efficient for both silica and fireclay bricks. This fact is particularly marked in the case of silica materials.
(3) A high porosity is not inimical to low diffusivity. Measurements indicate that at low temperatures with increasing porosity, decreasing temperature diffusivity is to be expected; while at high temperatures the reverse phenomenon often holds good. In general, it appears that the rate of increase of temperature diffusivity with temperature at high temperatures is greater in the case of materials of high porosity.

Many determinations of the thermal conductivity of silica and fireclay refractories, based either on the usual formula or on mathematical analysis, have been reported. There is, however, little concordance between the results of the various investigations. The following notes form a consideration of the factors influencing the thermal conductivity of silica and fireclay products.

(1) The value of this constant for a specific product increases with temperature.
(2) In recent years, there has been considerable discussion concerning the relative merits of silica and fireclay refractories as conductors of heat. This discussion, which has arisen from the increasing use of silica in coke oven and gas retort constructions, has been based on assumed practical experience, without reference to the actual determination of the co-efficients of thermal conductivity of these materials. The opinion

has been consistently expressed that silica brick is a better conductor than firebrick. From the early investigations of the present author[39] this

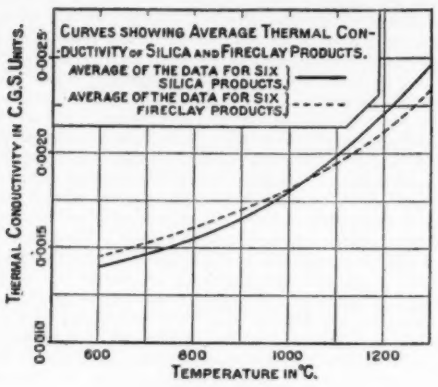


Fig. 11.

statement did not seem to be true. In fact, so much variation between individual products was found that it appeared definitely incorrect to assert that one material was better than any other without the evidence of a test. The present position seems to be that, comparing superior products of each kind, there is little to choose between the two types at low temperatures (900° or so). However, since the rate of increase of conductivity with temperature is greater in the case of silica brick, the conductivity of this product at high temperatures is, in general, greater than that of fireclay goods. However, the temperature diffusivity of a well-burned silica product is on an average definitely greater than that of a fireclay product, particularly at higher temperatures—a fact which appears to account for the reputed effective thermal properties of silica refractories in the carbonizing industries. A study of figs. 10 and 11 will illustrate this point of view.

(3) From Wologdines[40], and the author's work[41], it appears that increasing the firing heat treatment within the limits of the production of a commercial product increases the conductivity of both silica bricks and firebricks. The thermal conductivity of poorly-fired silica bricks is particularly low. The presence of a large excess of cristobalite in a silica brick appears to favour the conduction of heat.

This argument seems to lead to the conclusion that, under the influence of industrial usage, the thermal conductivity of these products will increase. The present author investigated this problem on a semi-silica material containing 80 p.ct. of silica which had been in use for eighteen years, together with samples of the unused product. It was found that the thermal conductivity of the used material was considerably higher than that of the unused product. (Fig. 12.)

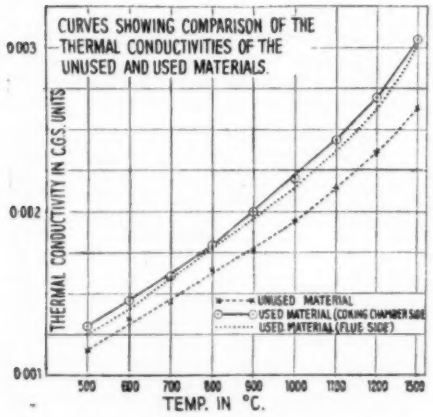


Fig. 12.

(4) The influence of porosity on the thermal conductivity of a refractory material has received considerable attention. It has been suggested that there is a relationship between thermal conductivity and porosity. While such a statement cannot be refuted (for, in part, it must be true), its limitations should be frankly recognized. In so far as the pore-spaces act as insulators, thus impeding the passage of heat, they have an influence on thermal conductivity. The term percentage porosity is used to indicate a measure of the pore-spaces, which naturally vary in size from easily-perceptible fissures to microscopic holes, many sealed off from the mass. The property of "pore-space" insulation depends on many factors, including temperature and the disposition, size, and shape of the pore-spaces. Now since the measurement of percentage porosity does not include knowledge of these factors, a quantitative relationship between porosity and thermal conductivity cannot be anticipated.

It has been stated that the transference of heat through the pores is very small compared with that transmitted through the solid matter—or, in other words, pore-spaces consistently maintain insulating properties. It would thus follow that the higher the porosity of a refractory material, the greater ought its insulating effect to be. This argument appears to be justified by the fact that such highly porous materials as diatomaceous earth bricks possess pronounced insulating properties at lower temperatures (*i.e.*, up to, at least, 700° C.), and thus under the accepted conditions of use. However, some investigators, notably Mellor[42], have, as the result of practical observations and theoretical deductions, suggested the hypothesis that, at high temperatures, heat may be transmitted, by way of the pores, at a rate which is comparable with that of conduction through the solid matter. In the earlier work of the present author, two facts seem to bear out this hypothesis. In the first place, the pronounced rate of increase in the value of the coefficient of thermal conductivity with temperature of some bricks at temperatures over 1000° was suggestive of influences additional to the conduction of heat through the solid matter. Again, a calculation based on the fourth-power radiation law and data obtained from the determinations of thermal conductivity showed that the rate of heat transmission by radiation across the pore-spaces at temperatures over 1100° may be at least comparable with the rate of conduction through the solid matter.

The present author's investigations[43] give definite evidence that in the neighbourhood of 1100° the rate of increase in thermal conductivity with temperature of certain materials possessing higher permeability to gases is greater than that of the less permeable materials. This evidence indicates that at high temperatures, the transmission of heat, by way of the pore-spaces, by convection and radiation is comparable with that by conduction through the solid matter, and that transmission by convection appears to take place to a much greater extent in the more permeable bricks.

## CONCLUSION.

The technology of clay and silica products has progressed considerably during the past decade or so. Much of this progress has been realized in the laboratory, and fundamental data of importance to the industrial usage of these products have been obtained. Further research, however, is vitally necessary, since the more precise our knowledge of these materials, the greater will be the fuel conservation and the economy of high-temperature operations.

Going hand in hand with the investigation of fundamental properties, the definition of the actual conditions obtaining in industrial usage is an essential. Up to the present, this phase of the work has not received much attention—in fact, it is an exceptionally difficult subject—but a greater realization of its importance is becoming evident. The fact that many apparently superior products have failed in specific duties, whereas the so-called inferior material has given comparative success in the same field of application, has emphasized the necessity for adequate definition of working conditions. It is evident, therefore, that refractory materials are not yet amenable to very definite specifications. Actually, that stage of the science of selection which has for its basis an adequate appreciation of all the factors relating to the use of these products has not been reached. This state of affairs must be overcome in the near future, if the refractories industry is accurately to meet its demands.

Finally, the author wishes to thank his employers, the Derbyshire Silica Firebrick Company, Ltd., for the privileges they have extended to him in the pre-

paration of this paper. He owes a debt of gratitude to his friend and late colleague, Mr. A. J. Dale, B.Sc., of the British Refractories Research Association, for permission to use a number of diagrams obtained in recent research work, and to use liberally the matter of certain recent publications.

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**Paper M. Session IV.**

# Gas Liquor Effluents.

**By A. PARKER, D.Sc., F.I.C., M.I.Chem.E.**

The satisfactory treatment and disposal of trade effluents, sewage works effluents, &c., is a general problem the solution of which becomes more urgent every year with the growth of industry. Those rivers which pass through industrial areas are already much polluted, and may become worse unless determined efforts are made to reduce to the minimum the quantities of harmful effluents admitted. Further, with the expansion of industrial operations, it is important that every reasonable precaution should be observed to preserve the few clean rivers now remaining.

It may be contended that polluting effluents should not be allowed, in any circumstances, to enter rivers; but in some instances this could not be accomplished by legal powers alone without necessitating the complete stoppage of industries employing large numbers of workers, since present knowledge is insufficient to devise methods of treatment of certain effluents except at costs which are greater than these industries could shoulder. Fortunately, the position is understood in responsible quarters, for the Department of Scientific and Industrial Research has set up a Board to advise on research into the problems of water pollution; and serious work has been commenced.

The object of this paper is to consider the problems involved in the treatment and disposal of the liquor effluents which result from coal carbonization industries, with special reference to the gas industry.

The most important effluents arising in the gas industry, as regards difficulty of disposal, result from the manufacture of sulphate of ammonia, concentrated aqueous solutions of ammonia, and anhydrous ammonia from the crude ammoniacal liquor collected in the cooling and condensing systems through which the gases and vapours pass after leaving the retorts. The usual product is sulphate of ammonia, but in the manufacture of all three ammonia products the resulting effluents are similar in character.

By the indirect and usual process of making sulphate, the crude liquor passes to the top of a vertical still, down which it flows and meets an upward current of steam. By simple boiling in this manner, the "free" ammonia is liberated, together with carbon dioxide, sulphuretted hydrogen, hydrocyanic acid, phenol, and pyridine. The "fixed" ammonia is set free by the addition of a strong alkali, generally lime, in the lower section of the still or in a separate still. The gases and vapours from the top of the still enter dilute sulphuric acid in a saturator, in which solid ammonium sulphate separates out. Excess steam and accompanying gases pass from the saturator through a heat exchanger, in which a portion of the heat is transferred to the crude liquor on its way to the still, and then through the condensers. The condensed steam dissolves some of the other compounds present, and the foul gases remaining are treated in purifiers containing oxide of iron, in Claus kilns, or by other methods.

The liquor effluents arising from the manufacture of sulphate ammonia by the indirect process are (i.) spent liquor from the still, and (ii.) "devil" liquor from the heat exchanger and coolers following the saturator.

## VOLUME OF EFFLUENT LIQUOR PER TON OF COAL CARBONIZED.

The volume of crude ammoniacal liquor obtained per ton of coal carbonized in gas-works practice varies considerably, and is dependent on (i.) the amount of moisture in the coal as charged into the retorts, (ii.) the water produced by distillation of the coal substance, (iii.) the quantity of steam admitted to the retorts and the efficiency of decomposition of the steam, and (iv.) the volume of water supplied to the scrubbers. It is, therefore, only possible to give very approximate figures to indicate the volumes and strengths of ammonia liquors produced by different systems of carbonization. As bases for estimates of the volumes of effluent liquors resulting from the manufacture of sulphate of ammonia, it might reasonably be assumed that the carbonization of one ton of coal in horizontal retort produces 33 gallons of ammonia liquor (9-oz. strength), equivalent to 25 lbs. of ammonium sulphate, and that with continuous vertical retorts supplied with steam, the corresponding volume of liquor is 50 gallons (7-oz. strength), equivalent to 30 lbs. of ammonium sulphate.

The volume of effluent liquor relative to the volume of ammonia liquor distilled is dependent on the strength of the liquor and on the efficiency of operation of the still, and varies greatly in practice. It might be assumed that with ammonia liquors of from 7-oz. to 9-oz. strength, the volume of effluent is 1·5 times the volume of liquor distilled. On this and previous assumptions, the total amount of effluent liquor (including devil liquor) per ton of coal carbonized, would be approximately 50 gallons for horizontal retorts, and 75 gallons for continuous vertical retorts.

## COMPOSITION OF EFFLUENT LIQUOR.

The composition of effluent liquor varies according to the composition of the ammonia liquor from which it is obtained. The constituents of ammonia liquor may be classified as (*a*) those salts which decompose on simple boiling and give rise to so-called "free" ammonia, (*b*) compounds which require boiling in presence of a strong alkali to liberate "fixed" ammonia, and (*c*) other compounds.

| (*a*) | (*b*) |
|---|---|
| Ammonium carbonate | Ammonium sulphate |
| ,, sulphide | ,, sulphite |
| ,, hydrosulphide | ,, thiosulphate |
| ,, cyanide | ,, chloride |
| | ,, thiocyanate |
| | ,, ferrocyanide |

(*c*)[1]

Pyridine salts
Phenols
Higher tar acids
Naphthalene
&c.

The compounds which give rise to the principal obnoxious constituents of effluent liquors are phenols, higher tar acids, the salts containing sulphur, and those containing cyanogen. The proportions in which these substances are present in the liquor vary considerably, according to the coal carbonized and the systems of carbonization, condensation, scrubbing, and storage. As an illustration of the character of the ammoniacal liquor from the storage wells of horizontal and vertical retort systems, as regards the most obnoxious constituents, the following figures are taken from the Sixty-First Annual Report of the Chief Inspector of Alkali Works.

*Ammonia Liquor from Storage Well.*

| — | Horizontal Retorts. | | Vertical Retorts. | |
|---|---|---|---|---|
| | Parts per 100. | In Terms of Oxygen Absorbed (O/A). Parts per 100,000. | Parts per 100. | In Terms of O/A. Parts per 100,000. |
| Monohydric phenols as $C_6H_5OH$ | 0·162 | 290 | 0·327 | 580 |
| Thiocyanate as CNS | 0·240 | 195 | 0·216 | 180 |
| Thiosulphate as S | 0·072 | 60 | 0·045 | 40 |
| Other bodies (including colour-producing bodies), by difference | .. | 65 | .. | 330 |
| Total | .. | 610 | .. | 1130 |

When ammoniacal liquor is distilled, the phenols, thiocyanates, and thiosulphates are retained by the effluent spent liquors. If it be assumed that as a result of distillation with steam, 100 volumes of ammonia liquor give rise to 150 volumes of effluent (still effluent *plus* "devil" liquor), then ammonia liquors of the compositions already given would produce effluent liquors of the following compositions.

*Effluent Liquor.*

| — | Horizontal Retorts. | | Vertical Retorts. | |
|---|---|---|---|---|
| | Parts per 100. | In Terms of O/A. Parts per 100,000. | Parts per 100. | In Terms of O/A. Parts per 100,000. |
| Monohydric phenols as $C_6H_5OH$ | 0·108 | 193 | 0·218 | 387 |
| Thiocyanate as CNS | 0·160 | 130 | 0·144 | 120 |
| Thiosulphate as S | 0·048 | 40 | 0·030 | 27 |
| Other bodies (including colour-producing bodies), by difference | .. | 43 | .. | 220 |
| Total | .. | 406 | .. | 754 |

The "devil" liquor usually constitutes 10 to 15 p.ct. by volume of the total effluent; the remaining 85 to 90 p.ct. consisting of spent liquor from the still. Since phenol is volatile in steam at 100° C., a large proportion of this compound passes into the "devil" liquor, which is consequently comparatively rich in phenol. Thiosulphate, thiocyanate, and higher tar acids are not readily volatilized, with the result that larger quantities of these substances appear in the spent liquor from the still than in the "devil" liquor. These points are illustrated by the following figures for the effluents obtained on distillation of a particular batch of ammoniacal liquor from continuous vertical retorts.

*Spent Liquor from Still and Devil Liquor.*

| — | Spent Liquor from Still. | | Devil Liquor (Filtered through Coke). | |
|---|---|---|---|---|
| | Parts per 100. | In Terms of O/A. Parts per 100,000. | Parts per 100. | In Terms of O/A. Parts per 100,000. |
| Monohydric phenols as $C_6H_5OH$ | 0·130 | 230 | 0·835 | 1485 |
| Thiocyanate as CNS | 0·525 | 435 | 0·02 | 15 |
| Thiosulphate as S | 0·060 | 50 | 0·01 | 10 |
| Other bodies (including colour producing bodies) | 0 35 | 275 | .. | 125 |
| Total | .. | 990 | .. | 1635 |

## INFLUENCE OF LIQUOR EFFLUENT ON STREAMS AND SEWAGE PURIFICATION.

Gas liquor effluent is usually brown in colour and turbid with particles of spent lime and tarry matters. By passage of the liquor through settling tanks, most of the lime readily separates out, leaving a liquid with a high affinity for oxygen. A discharge of this type has a detrimental effect on small streams, the water being rendered poisonous to fish and cattle, and unfit for many ordinary uses. The capacity of effluent gas liquor for absorbing oxygen also retards the self purification which occurs in all streams under ordinary conditions.

Frankland and Silvester determined experimentally the amounts of oxygen absorbed by phenol, thiosulphate, and thiocyanate as measured by N/80 potassium permanganate solution at 27° C. for four hours, and obtained the following results:

*Oxygen Absorbed, Parts by Weight.*

| Unit Weight. | Experiment. |
|---|---|
| Phenol, $C_6H_5OH$ | 1·78 |
| Sulphur (in thiosulphate) | 0 856 |
| CNS (in thiocyanate) | 0·827 |

These figures are frequently employed, in conjunction with results of chemical analysis, to ascertain the proportions of the total oxygen absorbed by effluent gas liquor which may be assigned to individual constituents. The de-oxygenating power, as determined by N/80 potassium permanganate solution, does not necessarily give comparative figures as regards toxicity to fish life. The test, however, is simple, and does give an indication of the extent to which effluent liquor retards self purification if admitted to streams, or increases the work of sewage purification if admitted to sewers.

Presumably the actual work of purification of town sewage is approximately proportional to the quantity of oxygen required. The effect of effluent gas liquor on sewage disposal may consequently be evaluated with sufficient accuracy by comparisons of relative volumes and oxygen absorption values of the sewage and liquor. The oxygen absorption capacities of effluent gas liquors range from 300 to 1000 parts per 100,000, whereas the corresponding figure for an average domestic sewage is 10 parts per 100,000. The volume of effluent gas liquor is generally very small relative to the average dry-weather flow of sewage. In districts where the gas-works serves the same area as is served by the sewage works, and no special circumstances arise, the volume of effluent gas liquor to be treated is normally less than 1 p.ct. of the volume of sewage. As an example, if it be assumed that a gas liquor effluent with an oxygen absorption capacity of 600 parts per 100,000 is added to sewage with an oxygen absorption value of 10 per 100,000, in the proportion of 0·5 p.ct. by volume, then the actual work of purification would be increased by 30 p.ct. as a result of the addition.

## METHODS OF PURIFICATION AND DISPOSAL OF EFFLUENT LIQUOR.

Effluent gas liquor might be purified either by the removal of the objectionable constituents by physical or chemical methods, or by the conversion of these constituents by chemical, biological, or other means into substances which do not absorb oxygen. The principal methods which have been proposed will be briefly described.

1.—*Bacterial Oxidation of Mixtures of Sewage and Gas Liquor Effluent.*—Ordinary sewage contains the active agents required for its purification in the bacteria which break down the complex organic matter present in the sewage to simpler substances. Chemical and physical actions also operate; but sewage purification, whether by land filtration, contact beds, sprinkling filters, or by activated sludge processes, is chiefly the result of the activities of bacteria, especially of the aerobic class.

Long experience in many towns has proved definitely that sewage containing spent gas liquor in normal proportions can be satisfactorily treated by ordinary methods of biological filtration, though the presence of effluent gas liquor necessitates an increase in purifying area. To ensure satisfactory treatment, the conditions of purification should be adequately controlled, and large and sudden changes in the proportion of gas-works effluent should be avoided. In most instances, plant for the manufacture of sulphate of ammonia is not run continuously throughout the year, but for periods of several weeks at a time, with intervening periods when the plant is out of operation.

In such circumstances, gas liquor effluent cannot be admitted continuously to the sewers unless storage or balancing tanks are available to allow for periods when the sulphate plant is out of action. The large reductions in sewage flow during night hours should also be considered.

As the result of an investigation of methods of purification of sewage, Frankland and Silvester* concluded that by providing a large area of beds, giving triple contact and permitting only a diminished flow of sewage on the beds, satisfactory purification can be effected of any proportion of gas liquor up to 9 p.ct. of the sewage flow. Wilson and Read also conducted laboratory experiments on sewage containing 8 p.ct. of gas liquor effluent, using percolating filters and the activated sludge process. Though purification could be effected by the activated sludge process, the results were not so satisfactory as with the percolating filter.

2.—*Bacterial Purification of Gas Liquor Effluent without Admixture with Sewage.*—G. J. Fowler† and his collaborators carried out an extensive series of experiments to determine the degree of purification of gas liquor effluent possible by bacterial filtration. Percolating filters were first matured by treatment with sewage, and the filters were afterwards employed in the purification of gas liquor effluent diluted with water. When the effluent from the filters showed a purification of 80 p.ct. of the diluted liquor, the treated effluent was used in place of water as the diluent. In experiments carried out at the Bradford Road Works of the Manchester Corporation Gas Department, one volume of gas liquor effluent was diluted with nine volumes of treated effluent, and the rate of flow was 100 gallons of diluted liquor, equivalent to 10 gallons of original spent gas liquor per day, per cubic yard of filtering material. The purification obtained was 92 to 98 p.ct. calculated on the undiluted liquor, and the oxygen absorption value was reduced from 500 parts per 100,000 to between 10 and 40 parts per 100,000. This amount of purification would not be sufficient to allow the treated effluent to be run into streams of small volume, but a discharge of this type in usual proportions would have no appreciable effect on sewage disposal if admitted to sewers. The Fowler system was put into operation at the Bradford Corporation Chemical Works about 1908, and during the first few years the degree of purification obtained was similar to that obtained in the experiments at Manchester. It is interesting to note that during their investigations Fowler, Ardern, and Lockett isolated a special organism which oxidizes phenol.

Small-scale experiments on bacterial purification of gas liquor effluent have also been carried out by Wilson and Read‡; and other experiments are described in the 60th Report of the Chief Inspector of Alkali Works.

3.—*Oxidation of Gas Liquor Effluent by Chemical Means.*—It would appear possible to purify gas liquor effluent by various oxidizing agents, such as ozone, hypochlorites, &c. Experiments so far conducted, however, have not shown promise of success as large-scale propositions. Frankland and Silvester§ examined the action of bleaching powder in presence of sulphuric acid, but even with as much as 0·3 lb. of bleaching powder per gallon of effluent liquor, the oxygen absorption figure was reduced only from 300 to 165 parts per 100,000, representing a purification of less than 50 p.ct. W. McD. Mackey has succeeded in purifying gas liquor effluent by means of ozone; but the method is too expensive for industrial purposes.

4.—*Extraction of Phenols by Solvents and Absorbents.*—Many processes have been devised and patented for the extraction of phenol and similar bodies from ammoniacal liquor and effluent liquor by solvents and absorbents. If processes of this type could be made satisfactory on the large scale, the oxygen absorption capacities of gas liquor effluents could in many instances be reduced by 50 p.ct. The solvent usually employed is commercial benzole, though trichlorethylene, and light tar oil previously washed with a solution of caustic soda until the tar acid content is less than 1 p.ct., have also been used.

In several installations erected in America‖, crude ammonia liquor flows downwards in series through two extractors, and benzole flows in a reverse direction. The benzole, containing phenol, &c., is then washed with solutions of caustic soda, and the liberated benzole is recirculated. The sodium phenolate solution obtained also contains cresols, higher tar acids, benzole, pyridine bases, naphthalene, &c. Benzole, pyridine bases, and naphthalene are removed by steam distillation, and the tar acids are liberated from the steamed solution by sulphuric acid or carbon dioxide.

In a plant erected at Hattingen by the Bamag-Méguin A.G.*, the ammonia liquor is preheated to 65° C. before extraction with benzole. The benzole-phenol mixture is then heated to 80° C. in a distillation apparatus; the benzole vapours being passed through a rectifying column and dephlegmator. The phenol tar remaining is distilled to remove the last traces of benzole. A statement of costs given shows a net profit of 14 p.ct. on capital investment, with a recovery efficiency of about 75 p.ct., when using a liquor containing 0·3 p.ct. of phenol. No allowance, however, seems to have been made for the loss of benzole which must result from its solubility in the liquor.

D. W. Parkes† has described the results of laboratory experiments in which phenols are removed from effluent gas liquors by means of activated carbon.

The processes designed for the removal of phenol by solvents and absorbents require further examination before definite opinions on their value can be given.

5.—*Removal of Phenol and Colour by Flue Gases and Steam.*—Gas liquor effluent is generally slightly alkaline, and the colour can be destroyed by rendering the liquor acid. By the passage of steam and hot flue gases through the liquor, provided the temperature be maintained above 90° C., the colour can in most instances be removed, and at the same time a large proportion of the phenol, $C_6H_5OH$, can be volatilized. The most satisfactory results by this method were obtained at Hornsey Gas-Works‡, where decolourizing and dephenolating towers have dealt with the effluent liquors produced in the manufacture of 2½ to 3 tons of sulphate of ammonia per day. Analyses indicated a volatilization of 71 p.ct. of the phenols and a reduction in the figure for oxygen absorbed of 42 p.ct. This method can only remove the volatile phenol, and not the higher tar acids; and in many instances the colour is only removed temporarily, for on mixing with sewage or streams the acidity gradually disappears and the colour returns. Vertical retort effluent liquors contain large proportions of higher tar acids, so that the maximum possible improvement cannot be so great as that obtained at Hornsey with liquor from horizontal retorts.

6.—*Removal of Thiocyanate.*—Several methods have been devised for the partial purification of effluent gas liquor by the removal of thiocyanate. In some processes the effluent liquor is first acidified by treatment with carbon dioxide or sulphur dioxide, and cuprous thiocyanate is afterwards precipitated by addition of cuprous oxide or copper sulphate. According to one method, mineral acid is added to the liquor, and thiocyanic acid is removed by the injection of air and steam; the thiocyanic acid is collected as aqueous solution in condensers. The processes tried on the large scale have not proved to be very satisfactory, largely because they are too expensive and troublesome in consideration of the degree of purification effected.

7.—*Evaporation of Gas Liquor Effluent.*—One method of disposal of effluent liquor is by evaporation to dryness; but unless waste heat is available for the purpose, this method must be expensive in fuel. For example, assuming the volume of effluent liquor from vertical retort systems to be 75 gallons per ton of coal carbonized, approximately 1 cwt. of solid fuel, on the basis of 7 lbs. of liquor evaporated per lb. of fuel, would be required per ton of coal carbonized. At certain coke oven installations, effluent liquor is evaporated by use in the quenching of coke.

In some gas-works, the devil liquor, the volume of which is from 10 to 15 p.ct. of the total effluent liquor, is evaporated by injection in the form of a fine spray into the base of a hot chimney. The procedure reduces the difficulties by an amount greater than that equivalent to the volume of devil liquor, since the oxygen absorption capacity of devil liquor is much greater than that of still effluent. Other methods of evaporation include spraying on to a burning spoil bank or into producer furnaces.

It is usual practice to supply water or steam to the

* J.S.C.I., 1907, **26**, 231.

† J.S.C.I., 1911, **30**, 174, 180, 181.

‡ J. Roy. San. Inst., 1912, **33**, 522, and Reports to West Riding Rivers Board.

§ *Loc. cit.*

‖ R. M. Crawford, Ind. and Eng. Chem., 1926, **18**, 313; 1927, **19**, 966.

* "Gas World" Coking Section, 1926, **173**, 20.

† J.S.C.I., 1927, **46**, 186T.

‡ T. L. Bailey, 59th Report of Chief Inspector of Alkali Works.

producers of retort settings, for the purpose of controlling the temperature of the bed of fuel and minimizing the formation of clinker. The amount of steam which passes into the producer is generally about 50 p.ct. of the weight of fuel consumed, or approximately 7 p.ct. of the weight of coal carbonized. If the water or steam ordinarily employed were replaced by effluent gas liquor, therefore, about 15 gallons might in this way be evaporated per ton of coal carbonized, or from 20 to 30 p.ct. of the total volume of effluent. Further examination of this method of disposal would appear desirable.

### MODIFICATIONS IN MANUFACTURE WITH THE OBJECT OF DECREASING THE AMOUNT AND IMPROVING THE COMPOSITION OF GAS LIQUOR EFFLUENTS.

The liquor collected during the carbonization of coal results from the moisture accompanying the coal charged into the retorts, the water formed on distillation of the coal substance, and water supplied to the scrubbers. With steamed vertical retorts the quantity of liquor is also increased by the steam which passes through the retorts without undergoing decomposition.

The water formed by distillation of the coal substance, usually in the neighbourhood of 10 gallons per ton of coal, cannot be reduced without radical changes in the carbonization process; and the water from undecomposed steam cannot be eliminated when steaming is practised, but it can be kept to the minimum by ensuring optimum steaming conditions.

Different types and qualities of coal contain different amounts of moisture. Washed nuts frequently contain 10 to 12 p.ct. of moisture, equivalent to 22 to 27 gallons per ton. Air-dried coal retains, at ordinary temperature, from 1 to 7 p.ct. moisture, or 2 to 16 gallons per ton.

*Acid Washer.*—The installation of a washer supplied with dilute sulphuric acid in place of the usual water scrubber reduces the volume of liquor by the amount of water ordinarily supplied, since the acid liquor from the washer may be used in the saturator of the sulphate plant. In the absence of complete data it is difficult to ascertain the reduction in the total oxygen absorption figure (total volume of liquor × O/A per 100,000) of the effluent which would result from the use of acid; but there would be a reduction, since aqueous solutions of ammonia dissolve sulphuretted hydrogen and hydrocyanic acid to produce salts which on oxidation under certain conditions give rise to thiosulphate and thiocyanate. In some instances, no reduction in volume could be effected by the installation of an acid washer, since the ammonia scrubbers are not supplied with water, but with ammonia liquor from the main storage well. This use of ammonia liquor, probably containing hydrosulphide, removes hydrocyanic acid from the gas and increases the quantity of thiocyanate in the effluent liquor.

Grossman and Wild* remove only free ammonia from the ammonia liquor in the still, and employ the still liquor in the scrubbers until the concentration of ammonium salts, &c., is sufficient to repay recovery.

*Direct Ammonia Recovery.*—This method of ammonia recovery is frequently adopted in coke-oven practice. The plant is usually arranged in the order, coke-oven, foul main, cyclone tar extractor, centrifugal or dynamic tar extractor, exhauster, saturator, naphthalene extractors, water-cooled condensers, &c. The plant is so designed that the temperature of the gas is kept above 70° C. until it leaves the saturator and enters the water coolers. Tar and fixed ammonia liquor condense out in the sections prior to the saturator. The fixed ammonia liquor, after separation from tar, is circulated through the tar extractors until it attains the desired strength, when it is sold as concentrated fixed ammonia liquor, or is evaporated for the production of crude ammonium chloride. A small quantity of tar collects on the surface of the liquid in the saturator, but is readily removed. Since the gas, as it leaves the saturator, is saturated with water vapour, from 20 to 30 gallons of aqueous liquor per ton of coal carbonized, together with some light oil, separate out in the condensers.

The only effluent to be dealt with is the liquor which collects in the condensers, with the exception of an almost negligible quantity of mother liquor produced if the fixed ammonia liquor is evaporated for the separation of crude ammonium chloride. A sample of liquor taken from the condensers of a coke-oven installation operating direct ammonia recovery methods gave the following typical results on analysis:

| | Grammes per 100 c.c. |
|---|---|
| Ammonia | 0·051 |
| Cyanide as HCN | 0·006 |
| Thiosulphate as S | 0·020 |
| Sulphide as $H_2S$ | 0·004 |
| Thiocyanate as CNS | 0·024 |
| Phenols as $C_6H_5OH$ | 0·630 |
| | **Parts per 100,000.** |
| Oxygen absorbed— | |
| Calculated | 115 |
| Determined | 1246 |
| Difference | 88 |

The phenols present, 0·63 p.ct., account for 90 p.ct. of the total oxygen absorbed value as determined by potassium permanganate. It might be possible to develop an economic process for the extraction of phenol from a liquor of this composition.

The direct recovery of ammonia has been tried in gas-works with usual types of carbonization systems, but the installations did not prove to be satisfactory. The demand for gas which has to be met by the average gas undertaking varies considerably, and a saturator cannot be operated successfully with large fluctuations in rates of gas production. With low rates, salt deposits on the curtain plates of the saturator, and causes stoppages. It is probable that the usual type of saturator might successfully be replaced by an acid washer in which the strength of the solution is kept below saturation-point. The solution could then be withdrawn as necessary, and evaporated for the recovery of salt. In connection with the possible application of methods of direct ammonia recovery to gas-works practice, it should be pointed out that the quantities of sulphuretted hydrogen, hydrocyanic acid, and carbon dioxide in the cooled gas would be greater than when ammonia liquor is allowed to condense as in usual practice, since ammonia liquor dissolves a proportion of these gases. Greater purifying area would, therefore, be required if direct ammonia recovery were adopted.

*Early Separation of Tar and Liquor.*—Phenols and higher tar acids should be classed as tar, but they are to some extent soluble in liquor; and since the volum of liquor is greater than the volume of tar, it is usu to find a larger total quantity of the phenol, $C_6H_5OH$, in the liquor than in the tar. It would appear from the work described in recent reports of the Chief Inspector of Alkali Works, that the application in gas-works practice of methods of deposition of tar from hot gas, before it had cooled below 70° C., would result in reductions in the concentrations of higher tar acids in ammonia liquor; and to this extent the quality of the effluent liquor would be improved. The major portion of the tar should be removed from the gas before more than a small proportion of the aqueous vapour present could be condensed. The major portion of the tar could not, in most instances, be removed without the deposition of a small quantity of liquor rich in fixed ammonia; but by the rapid separation of this liquor from the tar, the amount of higher tar acids which could be dissolved by liquor would be reduced to the minimum.

The deposition of tar from the crude gas, at temperatures above 70° C., might be effected by a spray tar-extraction apparatus or by a cyclone tar extractor followed by centrifugal tar extractors according to the methods employed in coke-oven installations in which ammonia is recovered by the direct process. Electrostatic methods of precipitation of tar are also worthy of serious consideration. Existing information is insufficient to enable a reliable opinion to be given as to which system of tar precipitation would be most satisfactory for the purpose, but the subject is being submitted to thorough investigation by the Gas Liquor Effluents Research Committee of the Institution of Gas Engineers.

*Minimum Contact of Liquor with Gas.*—It is highly probable that the thiocyanate found in ammonia liquor is largely the result of interaction of oxygen, sulphide, and cyanide (61st Alkali Report). The conditions which favour the formation of thiocyanate also favour the formation of thiosulphate. This has been shown by analyses by E. Linder of the same liquor before and after storage for six months. From these analyses it was found that in the liquor after storage, larger proportions of the total sulphur were present as thiocyanate and thiosulphate.

It has already been mentioned that the circulation of ammonia liquor from the storage well through scrubbers removes hydrocyanic acid from the gas and increases the quantity of thiocyanate in the liquor. It would, therefore, appear that an improvement in the composition of gas liquor effluent might be made by rapid cooling of the gas (already freed from tar at 70° to 80° C.) and rapid removal of liquor from the condensing system. The circulation of liquor in mains and scrubbers should be reduced to the minimum.

* J.S.C.I., 1906, **25**, 411.

Storage arrangements for liquor should be such as to allow minimum contact with air, and for the same reason the liquor should be distilled as early as possible, and long periods of storage avoided.

### SUMMARY AND CONCLUSIONS.

The most important effluents arising in the gas industry as regards difficulty of disposal result from the manufacture, by indirect processes, of sulphate of ammonia, concentrated aqueous solutions of ammonia, and anhydrous ammonia from crude ammoniacal liquor. Generally, the volume of effluent which results from the distillation of the ammonia liquor ranges between 45 and 75 gallons per ton of coal carbonized.

The effluent consists of liquor from the still, 85 to 90 p.ct., and devil liquor from the coolers, 10 to 15 p.ct.

The objectionable constituents of effluent gas liquors include phenols, thiosulphate, thiocyanate, higher tar acids, and other substances which absorb oxygen and unduly retard self-purification of streams and increase the work of purification of sewage if admitted to streams or sewers in sufficient quantities.

The oxygen absorption capacities of effluent gas liquors range from 300 to 1000 parts per 100,000. whereas the corresponding figure for an average sewage is about 10 parts per 100,000.

In districts where the gas-works serves the same area as is served by the sewage works, and no special circumstances arise, the volume of effluent gas liquor is usually less than 1 p.ct. of the dry-weather flow of sewage. Sewage containing gas liquor effluent in this proportion can be satisfactorily purified by usual bacterial methods, including activated sludge processes, provided the conditions of purification are adequately controlled and large and sudden changes in the proportion of gas-works effluent are avoided.

Purification to the extent of reducing the oxygen absorption value by about 95 p.ct. can be effected, according to the method of G. J. Fowler, by bacterial filtration of gas liquor effluent without admixture with sewage. This amount of purification is insufficient to allow the treated effluent to be run into streams of small volume, but is ample to prevent any appreciable influence on sewage purification if discharged into sewers. The process, however, is expensive in initial outlay.

Evaporation to dryness of the whole or a large portion of effluent gas liquor may be possible in a few cases where an abundance of waste heat is available for the purpose. In many more instances, the devil liquor might be evaporated by injection as a fine spray into the base of a boiler or retort house chimney; the total work of effluent purification required can, by this means, be reduced by about 20 p.ct. In some instances, from 20 to 30 p.ct. of the total volume of effluent might be evaporated by spraying into producer furnaces. Other methods of evaporation include coke quenching and spraying on to a burning spoil bank, but these methods could not be applied generally.

Partial purification can be obtained by the use of dephenolating towers provided with steam and flue gases, but the process is expensive in steam in consideration of the comparatively small amount of purification which results. The processes designed for the removal of phenol and higher tar acids by solvents and absorbents require further investigation before definite opinions can be given.

According to usual practice in gas-works, the tar and liquor which collect in the various sections of the cooling systems situated between the retort house and the gas purifiers are allowed to flow into a common tar and liquor well. Improvements in the compositions of ammonia liquor and effluent liquor as regards obnoxious constituents should result from modifications in the condensing and scrubbing systems, designed (i.) to remove the major portion of the tar before the liquor condenses, (ii.) to effect the early separation of tar and liquor, and (iii.) to ensure minimum circulation of ammonia liquor in contact with gas.

The various proposals which have been made to improve the composition of gas liquor effluent and to effect its purification and disposal are being submitted to examination by the Gas Liquor Effluents Research Committee, formed for the purpose by the Institution of Gas Engineers.

In conclusion, it must be stated that the admixture of gas liquor effluent with sewage is the only satisfactory method of disposal known at the present time. The conditions of purification should be adequately controlled, and large and sudden changes in the proportion of gas liquor effluent in the mixture should be avoided, by the installation, if necessary, of storage tanks to allow for periods when the sulphate of ammonia plant is not in operation.


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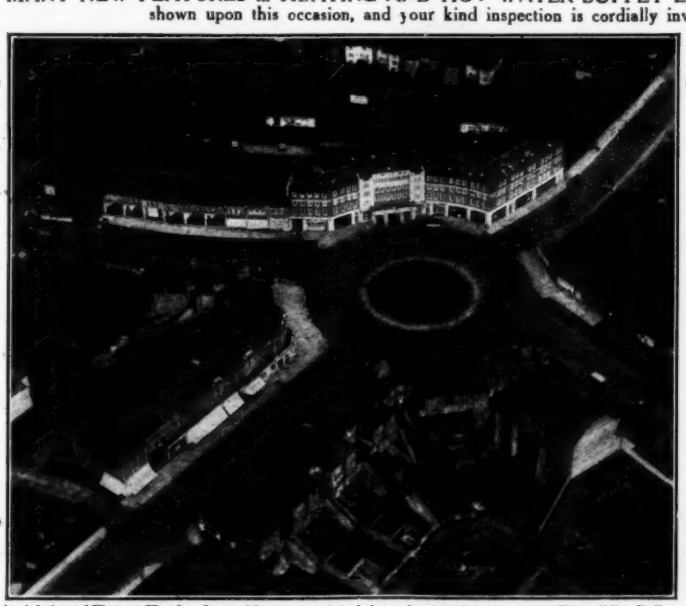

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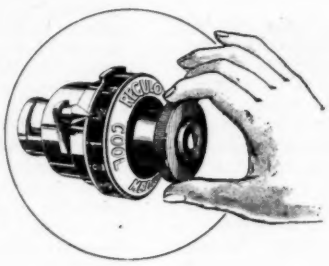


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**Paper N.**

# The Handling, Preparation, and Utilization of Gas-Works Coke.

By SIR ARTHUR DUCKHAM, K.C.B.

It has been pointed out on previous occasions that the gas industry is supplying already smokeless fuel in two forms—gaseous and solid—that is, as town gas and as gas coke.

The justification of a continuance of, and even an extension in, the production of gas coke may be found in several directions. The gas industry has not yet found that there is any method of producing town gas more cheaply than by obtaining a proportion of the heat of the coal as gas and disposing of the residue (after allowing for works requirements) in solid form as gas coke. It must also be realized that the greater part of the domestic heating in this country is carried out by solid fuel. Gas coke can meet this demand with a minimum alteration to existing firegrates and with consequent advance towards the ideal of the smokeless city. There is to-day an appreciable and rapidly increasing movement towards the adoption of central heating. A smokeless fuel is essential for this purpose, and a high-class coke fits the bill. Then, the national importance of the abolition of smoke demands that every known source of supply of smokeless fuel should be developed with the utmost vigour.

There is an immense field where gas coke can find an outlet. In 1925, the amount of coal used in this country for domestic purposes was about 40 million tons, and for general manufacturers 59½ million tons.

In that same year the total coke and breeze available for sale in this country was about 6½ million tons. Providing, therefore, that gas undertakings supply a coke of high quality, suitably graded, and that the selling thereof is efficiently organized, there is no fear of a restricted market, or that the entry of coke from other sources will necessarily mean less sales of gas coke.

It is the purpose of this present contribution to discuss two aspects of the coke question—namely, the means by which a high-class gas coke can be produced, and, secondly, the steps necessary to place it on the market to the best advantage of both gas undertaking and consumer.

### Requirements of a High-Class Gas Coke.

In a series of papers on the subject of gas coke written by engineers from all parts of the country and published in a special number of the "Gas Journal" (Nov. 9, 1925), almost complete unanimity was expressed that the requirements of a satisfactory gas coke were:

(*a*) Low ash.
(*b*) Suitable strength, density, and combustibility.
(*c*) Low moisture.
(*d*) Suitable size.
(*e*) Constant quality.

The first two requirements depend on the selection and pretreatment of the coal and on the method of carbonization; the second two depend on the treatment of the coke after removal from the carbonizing plant.

### Selection of Coals and Method of Carbonization.

The production of coke with low ash content is, in the opinion of the author, vital. Such a coke is a cheaper proposition to the consumer, as for a given outlay he receives a greater number of heat units. Less trouble is caused to the housewife. A coke containing 10 p.ct. of ash will entail the handling of at least 50 p.ct. more ashes and cinders when clearing the grate. Hodsman (J.S.C.I., 1927, Vol. 46, p. 92 T) has shown that in his experiments the highest efficiency of radiation was obtained with a coke produced at high temperatures in a static charge from coal with a specially low ash content. The coke contained only 1·5 p.ct. of ash.) The deadening effect of a coating of ash on the surface of burning coke is probably as great as, if not greater than, lack of draught.

Low ash content coke can only be produced from low-ash coals. Washed small coals are usually objected to by gas engineers on account of their high moisture content, but with the extension of dry cleaning methods there will be, in the near future, much greater supplies of dry cleaned coal.

It is probably not practical politics, except in comparatively rare instances, for coal to be cleaned on gas-works; but in one instance—the new plant at the Dawsholm Gas-Works of the Glasgow Corporation Gas Department—a coal cleaning plant is being incorporated.

Systematized mixing of coals will improve the ash content of the resulting coke. Most gas-works draw coals from more than one source of supply, and the ash contents may vary from time to time. If the various coals are received in bulk quantities and used as received, the ash content of the coke will vary from low to high. If systematic mixing be carried out, it would be possible to produce a coke with a constant ash content equal to the mean of that given by the coals.

Some solution may be found in purchasing coals on ash content, but probably the best solution is to cease taking supplies of coal with ash content above a certain figure.

### Methods of Carbonization.

Coke from continuous vertical retorts is of an open porous structure which, when supplied in a dry condition and suitably graded 1 in. to 2 in. in size, can be successfully used in open fires as well as in closed stoves. Static methods of carbonization, on the other hand, produce a denser coke which is more suitable, perhaps, for use in closed stoves and coke boilers. Its strength makes it acceptable for export.

Which form of carbonization is most suitable for the supply of coke to any particular district, depends on the relative demands for a coke for open grates and for closed stoves, industrial use, or export.

It is probable that, to produce from static carbonization a coke which will be wholly suitable for use in open grates, modification of the existing practice is required. The practice of denuding the coke of all volatile matter by long coking is inimical to its combustibility. This same practice has been openly challenged from the point of view of economical production of gas. It would appear to be a perfectly sound belief that, if by leaving a small proportion of volatile matter—say, at least 3 p.ct.—in the coke, a healthy and growing demand for coke for household purposes can be established, then such favourable prices may be obtained as to offset the slight loss in thermal production.

If, in addition to leaving the last traces of volatile matter in the coke, the coke structure can be modified by blending with non-coking coals, so that gas evolution is more rapid, then a new method of production of smokeless fuel is opened up. In recent experiments by the author's staff, blends of coking and non-coking coal have been carbonized in static charges in about two-thirds the normal coking time, and with the same high combustion chamber temperature as for complete carbonization. While the coke obtained from unblended coal with complete carbonization was more difficult to use in open grates, that from the blended coals ignited with ease from paper and wood, and gave fully adequate heating in the open grate of living rooms, entirely without smoke.

The blending process required is no different from that frequently installed at coke ovens abroad and

briquetting works at home. The ability to use non-coking coals would immensely increase the field from which the gas industry would draw its coal, and this would be reflected in a reduced price of gas coal.

### TREATMENT OF COKE AFTER CARBONIZATION.

Equal in importance to low ash content coke, and perhaps of greater importance, is the desirability of dry coke. The presence of moisture reduces materially the speed of ignition. It is not perhaps realized that the heat absorbed in evaporating a moisture content of 10 p.ct. is sufficient to raise the temperature of the dry coke approximately to 300° C., or roughly half-way to the ignition-point.

What is the best method of obtaining a dry or reasonably dry coke containing (say) not more than 5 p.ct. of moisture?

Perfectly dry coke can be obtained from continuous vertical retorts, or, in the case of intermittent processes, by the installation of a dry cooling plant. There are, however, many instances where an intermittent carbonization plant is installed, and where a case cannot be made out for the capital expenditure entailed in the adoption of a dry cooling plant. The author would suggest in such cases a study of the methods of quenching used on modern coking plants.

The principle adopted is that of having a definite relationship between the amount of water used and the amount of coke quenched. With bulk carbonization such as in coke ovens, intermittent vertical chambers, and inclined chambers, the amount of coke quenched at a time is generally constant (being one chamber). By applying a definite quantity of water, over-quenching can be avoided. It is usual, in the case of coke ovens, to lay out the coke on a wharf after quenching, before transporting it to the screening plant. By this means any hot spots can be quenched, and a minimum amount of water can be used in the quenching tower.

With horizontal retorts, where hot coke is handled by telpher, the same procedure—that is, using a definite amount of water per basketful of coke—can be adopted. It is suggested that the practice of dipping a basketful of red-hot coke in a water bosh is to be deprecated, as no regulation of quenching can be assured.

### GRADING AND COKE HANDLING.

Many gas undertakings are finding the advantages of offering coke for sale in several sizes. This is necessitated by the different purposes and the varying sizes of apparatus in which it is to be utilized.

It is not the purpose of the author to enter into a discussion on the relative merits of screens, but rather to suggest the main principles to be borne in mind when designing screening plants.

There appear to be, in the main, three principles:

(1) Control of the rate of feed to the screens.
(2) " Scalping " the unscreened coke—*i.e.*, divide it first into two parts (say, over and under 2 in.), and then rescreen these two parts into as many grades as is desired.
(3) Handling gently the large sizes of coke after they have been screened—*i.e.*, from screens into bunkers and from bunkers into trucks or carts.

Observation of the two former principles will enable maximum efficiency of the screens and the closest grading of the sizes to be obtained.

Proper consideration requires to be given to the chutes leading from screen to screen, and from the outlet of the screens to the bunkers. Screened large coke is often subjected to drops of many feet. The breakage thus ensuing simply detracts from the efficiency of the screening and may involve rescreening of the product. It requires some broadmindedness on the part of a gas engineer for him to agree to the extra expense of special chutes for eliminating these severe drops. It is suggested that a primary expenditure in this direction is amply compensated for by the elimination of rescreening and the constant production of a clean grade of coke.

Advantage will also be obtained by a consideration of the means for loading trucks. Loading booms are frequently used on coke ovens where a screened product is essential; and the development in the gas industry of sales of *screened* coke (mostly without dust) appears to warrant their use.

### COKE SALES.

In the foregoing, an endeavour has been made to present the salient points in the production of a dry, graded gas coke of wide applicability to domestic and local industrial use. Progress has been, and is still being, made in technique. The author proposes to refer in conclusion to the organization of coke sales.

A consideration of this subject suggests that there are four important steps which are required in order to maintain a healthy sale of coke at a price commensurate with that of house coal:

(1) Standardization of product.
(2) Analysis of coke sales.
(3) Propaganda and advertisement.
(4) Co-operative coke sales.

### STANDARDIZATION OF GAS COKE.

Without standardization with respect to moisture, ash content, and grading, a stable price for coke is not possible of achievement. One illustration may suffice. In 1926, the coke delivered to the author's offices for use in the central heating boiler was analyzed. Five consignments from one source gave an average moisture content of 18·4 p.ct. and an average ash content of 10·2 p.ct., making the combustible matter 71·4 p.ct. of the coke purchased. The succeeding two purchases were made from another source, the average moisture content being 5 p.ct. and the ash content 8·5 p.ct., the combustible matter being 86·5 of the coke purchased. It is imposible to have an equitable standard price for these two cokes, for the one is worth at least 20 p.ct. more than the other.

### ANALYSES OF COKE SALES.

By this is meant a statistical knowledge of the uses for which the coke is sold in any area of supply. Where the coke is sold direct from gas-works to consumer, it is possible to maintain contact with the latter and to see that he is receiving the grade of coke best suited to his requirements. Where, however, sales are made through coke merchants, it is more difficult. Nevertheless, it is suggested that a detailed knowledge of the local market is required by the gas engineer, for the following reasons:

(*a*) It will prevent unsuitable grades of coke being sent to consumers.
(*b*) It will enable the gas engineer to see what potential outlets for coke are not at present being cultivated, and to arrange for the necessary propaganda and sales campaign.
(*c*) It will give the gas engineer the utmost help in deciding what type of coke is most suitable for his district; and he can then decide the type of carbonizing plant and screening plant required for any reconstruction.

### PROPAGANDA AND ADVERTISEMENT.

One need only ask that the same energy be devoted to coke sales as is at present given to the sale of gas. It is suggested that an intensive propaganda, based on the knowledge gained by the analysis of coke sales, cannot fail to stimulate the coke market. The author would refer to three forms the propaganda might take. Every advertisement for gas should embody also an advertisement for coke. When possible, the marketing of coke under a special name would be found advantageous. This is particularly applicable to the coke produced by the more modern types of carbonizing plant such as " vertical " coke, " chamber " coke, or " furnace " coke. The development of sales under special names is a legitimate and successful method, widely adopted in most branches of trade. It is suggested that its adoption would tend to bind consumers to the use of coke from one particular source, and constancy of sales is a prime desideratum.

The third line of propaganda is that of demonstration. Every gas showroom should include an example of hot water heating and an open grate using coke. It does not appear to be sufficient to sell a batch of coke to a consumer, and leave him to make a success or failure in its use. Some personal help should be available. In certain instances personal canvassing and demonstration in the home have been adopted with considerable success. Other methods of propaganda will suggest themselves to those responsible.

It is perhaps unnecessary to emphasize the importance of coke sales in the balance-sheet of a gas undertaking. The heat units in the coke sold average nearly twice the heat units in the gas sold, though the value of the gas sales usually averages at least four times the value of the coke sales. At the present time an increase of 1s. per ton in the selling price of coke affects the net cost of gas into holder by approximately 2 p.ct.

### CO-OPERATIVE COKE SALES.

A consideration of this subject is necessary for two reasons. We have the singular spectacle of gas

coke produced in one town being sold in another at the same time as the gas coke produced in the second town is sold in the first town, or farther afield. An examination of the problem, however, shows that the demand for a solid smokeless fuel is as local as the demand for gas. It can be taken that the average gas consumption is about 30,000 c.ft. per consumer per year. In producing this there is for sale about 1 ton of coke. But each gas consumer is probably using several tons of coal. Any gas undertaking should be able to find its outlet for coke among its own consumers of gas. Competition from outside affects adversely the price to the local gas-works, and also it is not particularly advantageous to the outside producer, as the cost of transport has to be allowed for in the price at the works. Such a state of affairs can only arise from the attitude of " get rid of the coke anywhere at all costs."

We have now co-operative tar selling schemes, a co-operative sulphate of ammonia federation, and in the coke oven industry a co-operative benzole association. Is the circle complete without a co-operative coke selling organization? This would necessarily be divided into regional sections. Its functions, as the author sees it, would be :

(A) To take over the canvassing for orders and the selling of all bulk quantities of coke (small quantities could still be handled at the works itself).

(B) To decide by agreement among the constituent undertakings on a standard price for gas coke within its region of operation.

(C) To provide a continuous propaganda for the use of coke.

(D) To give advice to the smaller undertakers with regard to the preparation of the coke, and to exercise some control over the standardization of the coke quality.

The desire of the coke oven industry for an outlet for their small coke makes it all the more necessary that an organization such as outlined above should be a joint undertaking embodying both the gas industry and the coke oven industry. In the author's view, it would appear that the systematic selling of coke would provide a tremendous impulse to the ideal at which both industries are aiming—that is, the " smokeless city."

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**Paper P. Session V.**

# Blending in the Gas and Coke Oven Industries.

**By JOHN ROBERTS, D.I.C.**

Considerable progress has been made in the carbonization industries in recent years; but in view of the large quantity of raw coal still used in this country, it is essential to accelerate the rate of progress. To accomplish this, efforts should be concentrated towards discovering ways and means of effecting an ever-increasing throughput of coal per retort, and extending the range of coals suitable for coking. Several avenues of research are open, such as improving the design of retorts, methods of heating, the composition of refractory materials, and so forth. These are receiving attention at the hands of many investigators. Another important line of advance is the preparation of coal prior to carbonization, which is the aspect of the subject to be dealt with in this paper. Attention will be drawn to the beneficial effects of blending coals, grading, removal of ash, and the drying of coals; and as one of the main objects is to obtain increased throughputs, these several aspects must be discussed in relation to their influence on heat penetration.

It will probably be granted that hitherto insufficient attention has been given to the preparation of coal for coking or gas-making. The coke oven manager selected his coals from those having strong coking properties, and having a volatile content ranging generally between 25 and 33 p.ct.—his main object being to turn out strong metallurgical coke. The gas engineer selected coals of rather higher volatile range, which coals, as a rule, produced more open cokes than the best coking coals. Having determined the most suitable coals for his purpose, the gas engineer (or the coke-oven manager) drew his supplies from the most favourable source. Speaking generally, the question of selection of coals received no further attention, so long as the gas yield, or coke yield, as the case might be, proved satisfactory. One of the objects of this paper is to raise the question as to whether the practice outlined above is best policy. Shall we continue to charge into retorts coking coals and gas coals " as received? " Are the advantages to be obtained from the careful selection and blending of coals sufficient to warrant general adoption? If we can answer the latter question in the affirmative, as will be attempted, it follows that the former must be met with a negative.

## THE COKING PROCESS.

It is advisable at the outset to describe briefly what takes place when a coking coal is subjected to heat treatment. For this purpose, the behaviour of an ordinary coking coal of (say) 28 p.ct. volatile will be considered. In the first place we give a simple illustration as to what may be observed on a coal fire. With a coal such as that mentioned, if the fire be watched it will frequently be observed that viscous tarry matter oozes out from the burning coal, generally along the bedding planes in the lump. Meanwhile the coal on the hot side is being converted into coke; but the tarry matter that goes to waste plays no part in the coke-making process. If a quantity of inert matter, such as sand, be placed in the path of the fluid, the latter will bind the sand into a coherent mass; but if the tarry stuff is merely allowed to remain subject to the heat of the fire, it will become decomposed after a few minutes, and the residue becomes of little further use.

This illustration indicates that an ordinary coking coal contains more binder than is required for the formation of coke, and that this surplus binder, formed in the plastic zone, travels in advance of the coke zone, and naturally flows in the direction of least resistance. Hence it appears along the bedding planes and cleavages in the coal.

This observation has been confirmed in coking experiments. The writer has before him a specimen of semi-coke in which the fuel has coked in rings. The mass has been subject to the resistance of a rotating rod in the centre of the charge, but this resistance was unequal. Consequently, the coke rings varied in thickness; being thicker where the resistance was least. During the experiment, the rod ceased rotating, and its end exerted pressure against part of the charge; and here it was observed that not only were the coke rings thinner, but that the surplus binder, not being allowed to pass inwards, escaped along the line of least resistance between the concentric rings, as will be observed from the photographs, fig. 1, (*a*) and (*b*).

### THE COKING STAGES.

Referring again to the coal fire, if a piece of half burnt coal be extracted, allowed to cool, and then examined, four stages in the coking process will be observed. A small fragment picked out of the fire for this description consists of mass of unaltered coal *a*, fig. 2, adjoining which is a zone of fused coal $\frac{1}{20}$ inch thick; this is the fusion zone. Next follows a layer having a tarry appearance *b*, and consisting of a relatively spongy zone, in which the excess binder of the coal undergoes decomposition. This is the plastic layer, and it is followed by a more compact layer of semi-coke. The edge of the fragment, which was heated at about 900° C., consisted of coke. These four distinct stages can readily be detected in the manner described, though authors generally have failed to note that the first stage is the fusion stage.

If carbonization has proceeded at right angles to a bedding plane, and the fragment is broken at the plane where fusion commenced, it will be observed that tiny globular masses of fused coal appear on this plane, showing that there occurs a definite

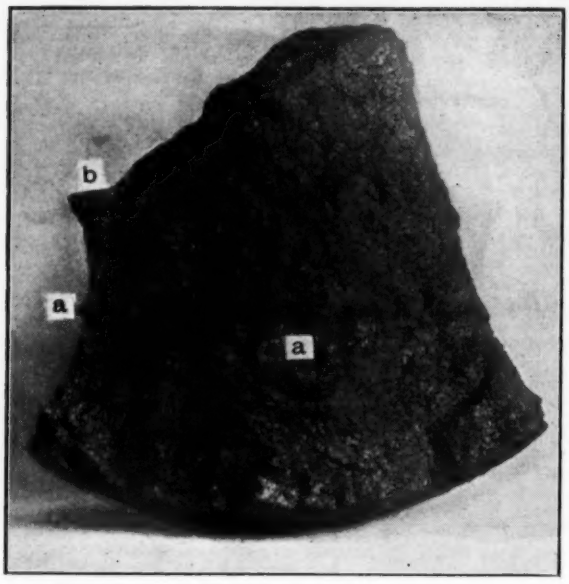


Fig. 1 (*a*).—Front face, showing ring formation and excess binder oozing out along line of weakness *a*. Rod exerted pressure at *b*.

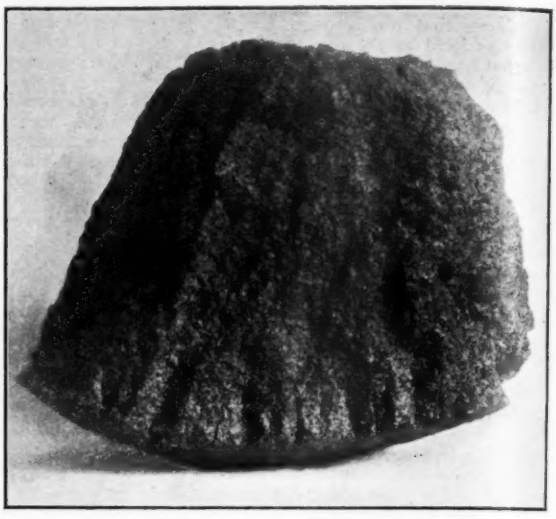

Fig. 1 (*b*).—Rear face. Lack of internal resistance allowed regular progression in coke formation.

change of form in the coal just before the plastic layer develops.

Another point to note is that in spite of the three stages *a*, *b*, and *c*, the transition from coal to coke takes place relatively suddenly, and the temperature gradient from the coal to the semi-coke zone must be comparatively steep, as the width along a line through the coal and semi-coke may be less than $\frac{1}{8}$ in. This is due to the resistance to heat penetration offered by the plastic layer.

The stages in coking are generally studied in the laboratory, where it is convenient to use charges of 200 grammes, or so, of 30-mesh coal heated in a fireclay crucible over a Meker burner. When this plan is followed, the zones appear as illustrated in fig. 3, in which *a* is the raw coal, *b* the fusion zone, *c* the plastic layer, *d* the semi-coke zone, *e* the high-temperature coke. The cells in zone *e* are smaller than in *d*, due to the fact that secondary contraction takes place at temperatures above 700° C. Using a Yorkshire coking coal, such as Thorncliffe, for example, the temperatures in the various zones would be approximately as given in the figure; but it will be borne in mind that the melting-points of coals vary.

### THE BEHAVIOUR OF THE BINDER.

If a feebly-coking coal be used instead of a strongly-coking coal, it may be extremely difficult to distinguish the zones above described. In fact, it is sometimes impossible to determine from an examination of the specimen exactly where coking begins; and no plastic layer is observed in such cases. Such coals do not swell during coking, and it has been found that they carbonize more speedily than normal coking coals, which fact again points to the resistance of the plastic layer. It has also been found that if the binder of strongly-coking coals be reduced by a preliminary heat treatment, such as oxidizing at temperatures ranging from 100° to 300° C., or by partial distillation for a short period at temperatures between 300° and 500° C., the plastic layer disappears, and the preheated coal may then be rapidly coked.

It follows from what has been stated that the development of the plastic layer is due to the formation in the coal during coking of more binder than is sufficient for the formation of a coherent coke, and that the elimination of the plastic layer results in increased speed of coking, and obviates swelling of the charge. One method of reducing the binder consists in preheating, but a better system consists in the employment of the binder for cementing inert carbonaceous materials which are otherwise non-coking. The inert fuels may be coke breeze, anthracite, steam coal slacks, and high-volatile non-coking coal.

Where coke breeze is available, it may readily be converted into saleable coke by mixing with good coking coal. Similarly in the case of anthracite fines, and the slacks of the steam coals of Wales and Kent; these are useful inerts when they can be obtained at a moderate price.

### UTILIZATION OF THE BINDER.

The proper utilization of the binder implies its employment in its proper function. Apart from the general advantages resulting from this procedure, there follows also the economic and national advantages arising from the extension of the range of coals which may be utilized in the carbonization industries. The use of non-coking coals has been very limited in the past, as most coke makers availed

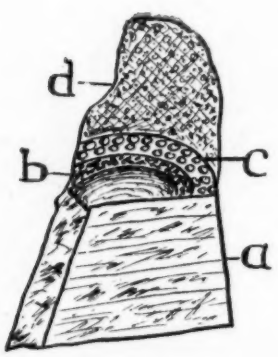


Fig. 2.—Stages observed when coking coal burns.

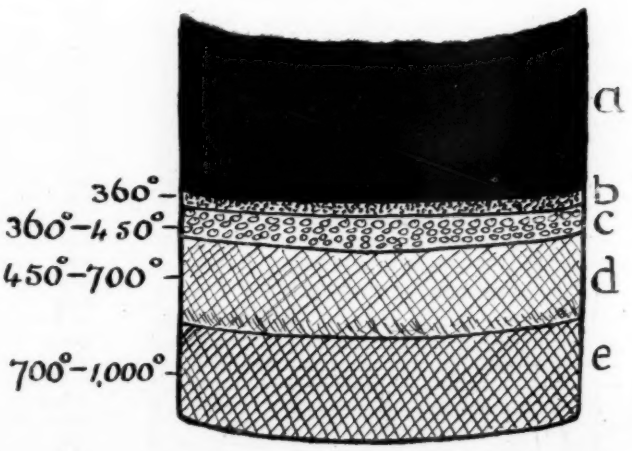


Fig. 3.—Coking stages observed in laboratory test.

themselves of the most strongly coking coals, concentrating only on blast-furnace coke production, and only in comparatively few cases were attempts made to find outlets for non-coking slacks. In several of these cases blends of both types of coal have been successfully coked. Nowadays, however, the coke oven manager turns his attention also to the domestic coke market; and this fact in turn must compel the gas engineer to intensify his efforts at improving his coke to meet competition. This rivalry will probably lead to the production on a large scale of carbonized fuels better calculated to meet the requirements of domestic consumers. The blending of coals is going to play an important part in this phase, because by this means not only do we extend the range of coals suitable for coking, but the use of inert non-coking coal in a blend makes it possible to produce at high temperatures a domestic fuel having remarkable combustible qualities.

### ADVANTAGES OF BLENDING.

A good deal of research has been carried out by several workers, as a result of which it has been shown that blending offers the following advantages:

(1) Prevents expansion of the charge during coking, and thus avoids sticking troubles.
(2) Eliminates or reduces the plastic layer, thus improving heat penetration, giving increased throughputs, and reducing cost of production.
(3) Rate of gas evolution and yields of gaseous therms per ton of coal can be enhanced.
(4) Coke and semi-coke of any desired texture may be produced, depending on the nature of the blends and the method of treatment.
(5) The crushing strength of coke may be modified to suit requirements.
(6) The range of coals available for carbonization is extended, resulting in the reduction of costs and the conservation of fuel.

To achieve these advantages, several factors have to be taken into account, depending on the carbonizer's objective. The question will be examined (*a*) from the coke-oven point of view, (*b*) from the gas-works standpoint.

## BLENDING IN COKE OVENS.

The objects here may be: (*a*) The improvement in the quality of coke; (*b*) the elimination of the compressing stage; (*c*) the production of readily-ignitable domestic fuel; or (*d*) the conversion of non-coking slacks into marketable fuel.

There may be cases where the adoption of blending may perhaps not improve the quality of the coke, but this will probably depend on the viewpoint of the producer or of the consumer; but since it can be demonstrated that suitable blending improves the product in most cases with ordinary coking coals, it may safely be assumed that even those coals which yield the best furnace cokes can be blended, at least without diminishing the value of the coke. It remains to be proved that the whole of the binder of the best Durham and South Wales coking coals is essential for the production of the famous furnace cokes.

The properties of many of the Yorkshire and Derbyshire coking coals can be improved by blending, which can be modified so as to increase the density or the toughness of the final product. High-volatile swelling coals have long been compressed, or stamped, prior to coking; but this is no longer necessary. It has been proved on the Ruhr that by the simple expedient of mixing semi-coke fines with coking coal, good furnace coke can be produced from coals which formerly required stamping. In Silesia the same procedure is adopted to produce suitable coke from coals which previously had to be blended with superior coking coals.

If it is desired to produce at high temperature a readily-ignitable coke, suitable for use in open grates in place of raw coal, blending will facilitate this operation, and in all probability will be found to be absolutely essential. This applies equally to coke oven and gas-works practice.

Where the object is merely the utilization of non-coking slacks produced at a given mine, the same precision in the matter of blending may not be essential, but it is generally advisable to exploit the possibilities to the fullest extent.

### GOVERNING FACTORS.

Where the use of high-oxygen non-coking coals is proposed, the following factors have to be borne in mind. In the first place, these coals give a relatively high yield of carbon dioxide and water of formation. It is to be anticipated, therefore, that the proportion of inerts in the gaseous yield will be higher than with coking coals. At the same time, it has to be remembered that as the yield of water of formation is greater with slow heating than with rapid heating, and as blending increases the rate of travel of the heat, the net increase in yield of water will be less than would appear at first sight. Another factor, which to some extent influences the rate of increase of temperature and the yield of water, is the exothermic nature of the reactions during carbonization, as high-oxygen coals are more exothermic at low temperatures than are low-oxygen coals. In any event, the quality of the gas will be found to meet requirements generally.

Water of constitution and high yields of $CO_2$ are given off from these coals at temperatures up to 500° C. or higher, but the more anthracitic a coal may be, the lower the yields of these products, until in the case of anthracite itself the yield is ***nil*** up to 500° C. Exothermic reactions are also absent below 500° C. with anthracite. Therefore, the considerations mentioned in the preceding paragraph may be ignored where the inert materials for the blends are anthracitic coals or low-volatile Welsh or Kent steam coals. These fuels can usefully be blended with coking coals; and the system offers a means of disposing of the slacks and converting them into excellent coke or semi-coke. But in considering whether to use them as inerts in blending, the yield of volatile therms must be taken into account. Physically and chemically anthracite behaves in every way as if it had been carbonized at 500° C. in the earth's crust under great pressure. Hence, it must not be expected to yield volatiles during carbonization at that temperature, so that the yields of gas and tar will be relatively low, but the yield of coke will be high. These facts will cause coke oven managers less apprehension than gas engineers, more especially where the surplus gas of the coke oven plant does not find a ready and profitable outlet. On the other hand, if gas engineers are intent on becoming the chief purveyors of solid as well as gaseous fuel, they may find it advantageous to turn their attention to the use of these low-volatile fuels, especially in Kent and South Wales.

Increased rapidity of coking characterizes judicious blending, whichever type of inert fuel is used; but in the case of inerts low in volatile content, the increase will be still further enhanced, owing to the fact that there is a smaller quantity of gas per ton of charge needlessly raised above its temperature of eduction. This applies to gas-works and coking practice, where the volatiles follow a path outwards through the charge; but where the volatiles travel inwards through the coal, as in the Hird system of low-temperature carbonization, the same argument does not hold.

Another point to note, where anthracite is used as the inert, is the peculiar physical structure of the coal, which is so dense that it does not allow the binder to penetrate it. Bituminous coals are less dense, and the binder penetrates to a certain extent. Coke breeze, of course, being porous, allows the binder to enter the cells and function as a cement. It is for this reason that coke dust in a blend toughens the product.

### KENT COALS.

The use of low-volatile inert coals is of peculiar interest to coke makers located in certain coalfields, in which Kent must now be included. The writer recalls that in discussing the so-termed "worthlessness" of a Durham cinder coal a few years ago, he remarked that such a fuel would be a godsend in the Kent coalfield, in which at that time only coking coals having extraordinarily strong coking and swelling properties were being worked. The position has already changed, as the latest pit to raise coal produces a coal having 15 p.ct. of volatile; the coal being almost indistinguishable from Welsh steam coal. A large proportion of this coal is slack, and one of the most promising outlets for this lies in its utilization in coking and gas-making plant.

### HIGH-OXYGEN COALS.

The question of blending is one of vital importance to coal producers in Kent, but on account of the wider distribution of non-coking high-volatile coals in other parts of the country, the matter must receive special attention outside the low-volatile coal areas. The blending of coking coals with lignitous coals has been practised in coking plants for many years, to a limited extent, chiefly in order to find an outlet for the slacks. Where the proportion of inert used

is low, no appreciable change in the properties of the coke is observed. As the proportion increases, changes in the structure become evident. One of these calls for special mention in connection with the properties of furnace coke.

### PROPERTIES OF FURNACE COKE.

Typical Durham furnace coke is steel-grey in lustre, dense in texture, and gives a relatively smooth fracture. The question arises as to whether these properties are inseparable from first-grade furnace coke, because, if they are, blenders will have to proceed with caution. The main requisite properties of furnace coke are: (1) Hardness and strength to withstand handling, charging into the furnace, and travel down to the combustion zone. (2) Resistance to excessive solvent action of $CO_2$ in the upper regions of the furnace. (3) Good cell structure, so as to ensure good combustibility in the combustion zone. (4) Uniformity in cell structure and size, and a minimum of cross fractures.

The hardness and strength of the coke can be controlled at will in blending. Therefore, the coke will not suffer on this account. The necessary deposit of graphitic carbon can also be controlled. Extreme density is not required, otherwise anthracite would not have been so readily displaced by coke; the cell structure must be such as to allow rapid combustion to take place. Now, while the three properties abovementioned can be retained in blending practice, it may be found in the case of certain blends—for example, Yorkshire coking coals mixed with large proportions of high-oxygen coals—that the coke may readily be distinguished from typical Durham furnace coke by its fracture, which, instead of being comparatively smooth, becomes rough and granular. This property, however, in no wise diminishes its combustibility. On the contrary, it improves the combustibility.

In this connection it is advisable to recall the views expressed in recent years by authorities on coke. Koppers ("Stahl und Eisen," 1922, Vol. 22, pp. 569-573) demanded that blast-furnace coke should be made at temperatures not exceeding 650° to 800° C., depending on the class of coal. It should, of course, be hard, but should give off volatiles freely when heated at 700° to 750° C. Sperr and Jacobsen ("Blast Furnace and Steel Plant," Aug., 1923, pp. 426-431) expressed similar views. Thau ("Chem. and Met. Eng.," 1924, Vol. 30, pp. 347-350) considered that the filling-up of the cells of the coke with graphite reduced the combustibility. Hence, he also suggested pushing the charge before carbonization was complete, so as to avoid over-coking and excessive deposition of graphite. He stated that a silvery appearance was favourable only inasmuch as it indicated a low moisture content; but beyond that, it indicated deposition of graphite

### GRAPHITIZATION.

It would appear from the foregoing that it is at least questionable whether one of the properties usually associated with superior furnace coke—namely, bright silvery lustre—is really desirable. However, some deposit of graphite is essential in order to give the coke the necessary strength, and this would be unavoidable if attempts were made to push coke-oven charges early, as the portions near the oven walls would become graphitized to a certain extent.

Graphitization can be controlled, the coking period shortened, and the charges pushed before carbonization is complete, if blending is adopted. This may or may not prove to be a step in the right direction in the manufacture of blast-furnace coke, but it will certainly be advantageous where it is desired to manufacture a readily-combustible domestic coke in coke ovens. It appears that Thau (*loc. cit.*) desired to see manufactured a hard coke possessing the reactivity of semi-coke, but that efforts to produce same had not been successful. Recently, however, a coke having combustible qualities equal to those of coalite, although not so readily-ignitable, has been produced on a works plant from retorts heated up to 1400° C., using a blend containing a large proportion of high-oxygen coal. In this fuel graphitization has not proceeded to the same extent as when the coals are allowed to become fully carbonized, as the deposition of graphite is due to secondary cementation resulting from the decomposition of hydrocarbons. By shortening the coking time, which is facilitated by blending, the hydrocarbons suffer less decomposition.

The work already done in this direction indicates that it will be possible to produce a very desirable domestic fuel under high-temperature conditions by the method described in a previous communication ("Colliery Engineering," 1925). The essential conditions are: Maximum flue temperatures, silica construction, retorts not exceeding 14 in. in width, blends to contain a minimum of surplus binder, and the ovens to be pushed when the middle of the charge reaches about 600° C. The sizes of coals to be used will vary according to the class of material, but generally speaking it will be found advisable to crush the coal to pass a ¼ in. mesh, in order to ensure adequate mixing.

### THE USE OF COKE BREEZE.

This fuel is an excellent absorbent for the excess binder of rich coking coals. Its use in suitable proportions increases the toughness and crushing strength of the resulting coke, it eliminates the plastic layer, prevents swelling of the charge, and facilitates heat penetration. If a coal yields a very dense coke, the coke can be "opened-up" to give it the necessary cell structure to ensure good combustibility; while coals which yield spongy coke can be made to give denser coke by the addition of breeze. The size of material used will vary according to requirements. Generally, the coke dust should pass a $\frac{1}{16}$ in. mesh, but larger material can be used if the normal coke is particularly dense.

It should be noted that the use of breeze does not diminish the real throughput of the retort, as the enhanced rate of carbonization more than counterbalances the reduction of capacity as a result of the introduction of breeze. Even though the charge may contain as much as 25 p.ct. of material which has already passed through the coking process, the throughput of *coal* will be increased under favourable conditions.

### TEMPERATURE OF CARBONIZATION.

Whichever class of non-coking fuel is employed, the temperature of carbonization must be taken into account in determining the proportions of the blend. The higher the temperature employed, the greater the amount of inert which may be used. Some feebly-coking coals will fuse only when rapidly heated at a high temperature, and provided they are not crushed too finely. Oxidation of the binder plays an important part in the process; and if the charge is likely to remain at a low temperature for a prolonged period, it will be found essential to increase the proportion of coking coal, to make up for the partial destruction of the binder which will take place while the charge remains at a temperature ranging from 100° to 300° C. This accounts for the fact that in some cases the addition of 10 or 15 p.ct. of inert will prove an advantage when operating at high temperature, but the addition of the same proportion of inert would prove a disadvantage if carbonization were carried out at 600° C. The blend must be determined in relation to the temperature employed in coking. To secure the maximum advantage, rapid heating is essential.

## BLENDING IN GAS-WORKS.

In general, the principles involved in blending apply equally to gas-works and coke oven practice, but the problem entails certain considerations in the former industry which are of less importance in the latter. The size of material calls for first consideration. It has already been stated that coal which passes a ¼ in mesh should be used in blending, as this makes for the production of coke of even texture. In gas-works, however, the use of fine coal retards the evolution of gas. Hence, nut coal is more generally used, as the quality of the coke has hitherto been regarded as of secondary importance. But in view of the severe competition which gas companies now meet with in the coke market, owing to the expansion of the sale of furnace coke for central-heating purposes, &c., gas engineers are beginning to realize that it is essential to improve the quality of the coke they produce.

### COAL GRADING.

The question of the size of coal most suitable for gas manufacture has received special attention from the late Dr. Geoffrey Weyman, Dr. A. Parker, and T. Carmichael. Weyman arrived at the conclusion that: "The size of particle is most important as interfering with the formation and continuity of the plastic layer. The larger the size of particle, the less continuous the plastic layer and the more rapid is the carbonization." He found that by increasing the sizes of coal, up to a point, the rate of gas evolu-

tion increased, and he considered that the size of the interspaces in the mass was of greater importance than the total free space (" Journ. Soc. Chem. Ind.," Vol. XL., No. 24, pp. 300-308T.). " With coal containing all sizes, the rate depends very largely on the difference between the maximum and minimum size. The more irregular the mixture, the better the results. Relatively small amounts of dust affect the rate very adversely; more so when the coal possesses an even gradation in size. For any size the following classes of coal are arranged in ascending order of maximum rate of carbonization; there being a gradual transition from class to class. Coking coals, gas coals, cannels, anthracitic coals, and non-coking coals."

The finer material offers resistance to the passage of gases, and sets up back-pressure in the retort. A more even pull can be maintained when larger sizes of coal are used. Further, the continuity of the plastic layer diminishes the transfer of heat by convection, whereas with larger sizes and interspaces convection comes into play.

Parker and his colleagues have carried out research on this aspect of gas-making. They used an experimental horizontal retort, and worked with coal of the following sizes: 1¼ to ¾ in., ½ to ¼ in., and 10 to 30 mesh; and it was found here also that the larger sizes gave a more rapid yield than the 10-30 mesh coal. (" GAS JOURNAL," June 22, 1927, p. 864.)

### EFFECT OF SCREENING IN PRACTICE.

These results have been confirmed on a works scale by T. Carmichael at the Portsmouth Gas-Works (" GAS JOURNAL," June 22, 1927, p. 844), where it has been the practice for a few years to separate the fines from the nuts, and to carbonize the nuts in Woodall-Duckham vertical retorts, and the fines in horizontal retorts. The results obtained are very striking. " Improvement has been found in every direction, the actual increase in the thermal output of the coal being 10 p.ct., and of the plant 20 p.ct.; and less sticking of the charge has been experienced. The production per ton of coal carbonized rose from about 62 therms with the unscreened coal to 69·1 with the screened coal, while in the horizontal house the total therms evolved from the smaller grade of fuel dropped only to 68·8 per ton as compared with 70·2 from the unscreened variety. . . . The output of one bed of vertical retorts rose from 860 to 1032 therms per day."

From the foregoing it will be seen that considerable benefits result from the removal of the dust from gas coal which is to be carbonized in continuous vertical retorts. It will be noted also that Carmichael stressed the fact that sticking troubles were avoided. Other gas engineers have found that these difficulties can be completely overcome in practice by mixing non-swelling or non-coking coal with swelling coals such as those of Durham, while Parker showed that by blending with coke breeze larger volumes of gas for the same weights of coal were obtained from coal-coke mixtures at all stages of carbonization.

### SIZING IN RELATION TO BLENDING.

Parker and Carmichael showed that the process of gas-making could be speeded up by removing the fines from the coal; and the former illustrated his results by means of graphs, which bear a striking resemblance to graphs published by E. V. Evans (Cantor Lectures, 1924). Evans, however, obtained his remarkable results by the use of briquetted blends, in which the inert material consisted of 25 p.ct. of coke dust. In both cases the rate of gas evolution was increased, (*a*) by separating-out the fines; (*b*) by blending with inert. The result of such procedure is that the efficiency of the gas-making process is considerably increased in the earlier stages. In order to take full advantage of this, it appears desirable to carry out the process as far as possible only during the period of maximum yields, and to cut out the inefficient periods where the yields of gas are low and hardly worth extracting.

This point can best be illustrated by means of examples, taken from actual runs on horizontal retorts. In a paper by T. Hardie (Proc. Inst. of Fuel, Vol. 1, p. 2), a heat balance shows that the energy put into the producer for heating the retorts amounted to 42 therms. Assuming a carbonization period of 10 hours (it varies from 8 to 12) this represents 4·2 therms per hour energy input. Comparing these figures with the results obtained by E. V. Evans (*loc.cit.*), it is observed that the yield of therms obtained from the briquetted blends fell to less than 4 therms per hour at the end of the fourth hour. Therefore, the energy input was greater than the thermal yield extracted from the charge after that hour. In other words, prolonging the process resulted in a waste of energy, and at the same time involved the complete extraction of the gas from the coke.

Hence it will be seen that a system which appears to be unprofitable to the gas engineer is also displeasing to the consumer who desires to use coke in domestic grates, since over-coking of the charge reduces the combustibility of the fuel. In discussing the question of the production of smokeless fuel with gas engineers, one is generally met with the objection that the value of the gas proposed to be left in the fuel runs to about 18s. The answer to that is that if blending were adopted, and the process worked only during the period while the efficiency reached a high level, it would not be found worth while working at the low-efficiency period. The question is not so much the value of the gas left in the coke as the relative costs of extracting the gas during the respective periods mentioned.

### STATIC AND NON-STATIC CHARGES.

While it will in many cases be found to be a sound economic policy to adopt the plan of screening, as at the Portsmouth and other gas-works, it follows also that it will in several plants pay to utilize fine coking coal mixed with non-coking coal, both of which grades are obtainable at less cost than ordinary gas nuts. The former system tends to the limitation of the selection of coals, while the latter plan enables gas engineers to draw supplies from a wider field, and at the same time encourages the recovery and production of coals not normally used for coking, which, for want of a suitable market, are often left unmined, thus making for the conservation of fuel resources.

The grading of fuel is undoubtedly advantageous in continuous vertical retorts, but it is essential that the slacks should also be carbonized. One ideal system is that to be employed at the Dawsholm gas-works, where the screened coal is to be carbonized in continuous verticals, and the finer material in intermittent vertical retorts.

Since it is essential when blending inert fuels to use material which has passed through a ¼ in. mesh, the system is not recommended for employment in continuous verticals. Where the coals to be blended are fusible, fine crushing is not essential, so that a highly-fusible coal may be blended with a less fusible coal for continuous verticals. In general, however, blending will be reserved for static charges, as in horizontals, intermittent verticals, and inclined chamber ovens. It is retorts of this type, and coke ovens, that are expected to prove suitable for the manufacture, at high temperature, of smokeless domestic fuel, suitable for general use in open grates.

## DE-WATERING OF COAL.

Another direction in which improvements and economies may be effected in carbonization is in reducing the proportion of water charged into the retorts with the coal. In coke-oven practice the use of washed coal is general, and the coal as it leaves the washery carries from 10 to 20 p.ct. of water, and when charged into the ovens it usually contains from 10 to 15 p.ct. In view of the fact that the volatiles and moisture of the charge pass outwards to the sides of the retort, it is obvious that the water has to be raised to the retort temperature, which approaches 1000° C. This involves a great waste of energy. Even in cases where the volatiles may be compelled to take an inward path, the evaporation of the moisture is still a source of loss of heat, though the loss is considerably reduced in such plant.

The main drawback in the use of wet coal is the retarding effect of the moisture on the coking process, as was shown by C. Lowthian Bell and S. Cooper (" Journ. Iron and Steel Inst.," 1904, Vol. 1, p. 198, and 1914, No. 2, pp. 46-47). Other serious disadvantages arise from the extra work thrown on the condensing system of the bye-product plant, and the damage to retorts through excessive water content.

The remedies lie in the use of dry-cleaning plant for de-ashing the coal, or the use of coal-drying plant where wet-cleaning processes are installed.

As illustrating the advantages resulting from de-watering coal, the experience gained at the Nunnery Colliery with the Carpenter dryer may be quoted.

When the proportion of water was reduced from 18 to 5 p.ct., it was found practicable to discharge 42 ovens per day, as against 34½ when the coal was not de-watered. Reducing the water content to 7½ p.ct. resulted in an increase of rather more than

15 p.ct. in the throughput. Appreciable financial advantages were effected through the use of the drying plant.

### DE-ASHING OF COAL.

The importance of reducing the proportion of ash in coal prior to carbonization cannot be too strongly emphasized. One of the chief reasons why coke-oven operators are able to make such great progress in the domestic coke market is the fact that oven coke is prepared from washed coal. Consequently, the ash content of the coke is lower than that of gas coke. Consumers readily appreciate this point. When serious attempts are made to replace raw coal with a smokeless fuel, the matter will become still more urgent, since, however great the advantages of smokeless fuel may be, if the ash content is even no greater than that of household coal, the consumer will probably object to it more strongly than in the case of coal. The reason for this is that with a smokeless fuel produced from coal that has been crushed to pass (say) ¼ in., the fuel burns away so completely as to leave only a fine ash in the grate. This material creates dust very readily if not carefully handled, as there are no heavy unburnt or partly-burnt particles of fuel to prevent the ash flying about. The finer the mesh of the coal employed, the more flocculent the ash, and the greater its apparent bulk.

It is essential, therefore, to concentrate on the use of coal which has passed through a cleaning process. For reasons already stated, dry-cleaning plants should have preference in new installations.

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**Paper Q. Session VI.**

# A General Review of Low-Temperature Carbonization.

**By F. S. SINNATT.**

The past ten years have been a period of great activity in the coal industries of this and other countries, and attention has been focussed upon the many problems associated with the utilization of coal. The interest taken by the public and technologists is reflected in the publication of a mass of technical literature and in the large number of inventions constantly being patented. It cannot be said that the scientific investigation of the problems encountered in the use of coal has kept pace with the commercial development of many of the processes, largely owing to the rapidity with which the problems develop and an insufficient supply of investigators possessing an adequate knowledge of the subject. Each method of treatment calls for some new knowledge of the coals, the tars, coke, &c., and frequently for the invention of new methods of utilizing particular products. In the case of low-temperature carbonization, we appear to be trying to perfect, in a generation, a process similar to the one on which the coal gas industry has spent over a century of carefully organized endeavour. The fundamental data required can only be obtained slowly, and frequently processes have to wait for sufficient associated knowledge to accumulate before a satisfactory interpretation of the results can be advanced. It is recognized as being practically impossible to translate the laboratory discoveries on coal into large-scale practice without passing through plants of intermediate scale, and conversely it is also extremely difficult to translate into terms of the properties and composition of the products the influence of the diverse conditions existing in large-scale plants.

Low-temperature carbonization has aroused the greatest interest, more particularly in this country; and well over two hundred separate methods have been described. In thinking of the developments which have occurred during recent years, it must not be forgotten that a great deal of the pioneer work upon the properties and uses of low-temperature coke, the constitution of the tars, &c., has been inspired by Low Temperature Carbonisation, Ltd.

The prospects of low-temperature carbonization generally are bound up with the coal gas industry and the coke oven industry, and also with the trends in industry, as they bear on the grades of coal available. Many of the low-temperature processes have been devised to treat small sizes of coal, with a view to "stepping-up" the value of the products obtained. It is frequently assumed that these grades of coal will be low priced. It is important to examine briefly the general position in relation to small sizes of coal and the saturation of the domestic requirements. There is undoubtedly a general increase in the demand for small coal; and many devices have been developed for the combustion of such grades of coal—*e.g.*, modern chain grates, special furnaces, pulverized fuel plants. The coal gas industry and the coke oven industry utilize these grades of coal in their normal processes.

The primary function of the coal gas industry is to supply town gas for domestic and industrial purposes as economically as possible. One of its chief products is gas coke, offered by up-to-date works in sizes suitable for many domestic purposes. The primary duty of the coke oven industry is to provide the special coke required in blast furnaces; and its chief secondary product is coke oven gas. In recent years the coke oven industry has recognized the domestic needs, and by careful grading of its coke competes with gas coke in the industrial and domestic markets. The coke oven industry is also co-operating to an increasing extent with the coal gas industry; and a number of districts are now receiving the whole, or a portion, of their coal gas from coke ovens situated in their neighbourhood. The two industries together utilize about 36 million tons of coal per annum, or about one-fifth of the home requirements. It is obvious that coal gas is the most perfect smokeless fuel, and that gas coke or coke oven coke is also smokeless, and satisfies a number of domestic requirements. The general effect of the cheapening of gas and an improvement in the quality of coke is to satisfy the domestic requirements and to decrease the demand for coal for domestic purposes. The effect of this trend is important because it has been the custom for collieries to offer certain grades of small coal at low prices, since they were able to demand a higher price for the sized coal. If the household market for the lump coal is filled by fuels made from small coal, whether coal gas, gas coke, coke oven coke, or smokeless fuel, the natural result will be an increase in price of the small coal until it bears its full mining cost. This conclusion is obviously of importance in considering the commercial possibilities of low-temperature carbonization, as it is both local and general in its action.

It is frequently overlooked that the coal gas industry in its development passed through a stage in which the process of carbonization was carried out at "low temperatures" in iron retorts, and that from a technical point of view, by modifying the processes in existence in many works, lump low-temperature coke can be made. Further, the work of Lessing and Cobb has indicated that it is possible to modify the properties of high-temperature coke and provide a product possessing greater activity; and this suggests a wider use of high-temperature coke for household purposes.

It would appear natural for the production of smokeless solid fuel, suitable in every way for domestic appliances, and coal gas and coke manufacture to proceed hand-in-hand, and for the coal gas and coke oven industries to become the domestic fuel industry in its widest sense.

The process of low-temperature carbonization has been before the gas industry for over twenty years; and as far as the author is aware only two plants are in operation on a large scale in gas-works. The above facts cannot be ignored in considering the commercial development of low-temperature carbonization in relation to the fierce competition to be expected from lump coal, coke, and gas, for the domestic market, and tar on the bye-product market.

The objects of the present paper are threefold—to provide an opportunity for discussion, to examine the products of the chief processes of low-temperature car-

bonization, and to collect together suggestions as to ways in which the products can be utilized. All the processes mentioned later yield products possessing certain definite characteristics; and there is no intention of suggesting that any method is superior in a general sense to others, since the commercial prospects will depend upon the process being placed in a suitable industrial environment. Markets of a dependable nature must be found for the whole of the products, together with a means of disposing of the effluents. It would appear that if industrialists will study the products of the various processes, they may find that some system is suited to certain peculiar conditions with which they are familiar. It must be remembered that practically every type of coal is mined in the country in large amounts, anthracite, steam-raising (non caking), coking and gas-making, non caking (with higher percentage of oxygen), splint coals, cannels, &c.; and since some 40 million tons per annum are used in the raw state for domestic purposes, and some 60 to 70 millions for general manufacturing purposes, there are opportunities for all of the processes for many years without their interests clashing, provided they can be made to pay.

Though so many processes for low-temperature carbonization have been suggested, the principles involved can be differentiated broadly; and the following are the plants of which, it is understood, a large-scale unit exists in this country, or is in course of erection.

### External Heating.

#### Mass of Coal Stationary.

*Parker Plant; Low Temperature Carbonisation, Ltd.*

The retorts are made of special cast iron, and consist of nests of vertical tubes 9 ft. high and tapering from 4½ in. at the top to 5½ in. at the bottom. The retorts are charged at intervals of about 4 hours, and the "coalite" is allowed to cool in a chamber in the absence of air.

The coal generally used is a washed slack from one of the best Yorkshire seams. The plant in operation is stated to have a capacity of 250 tons a day; and according to the Chairman of the Company, an agreement has been reached with the Askern Colliery, near Doncaster, for the erection at the pit-head of a plant capable of dealing with 500 tons a day.

*Illingworth Carbonisation Company, Ltd.*

The coals, or blends of coals, receive a pre-treatment to modify the swelling properties and bring them to a particular condition. This ensures uniform qualities in the smokeless fuel, though the tar and gas yield may vary. The retorts are built with **H** section cast-iron conductors in each retort. The time of carbonization is 5½ hours. The hot smokeless fuel is cooled by bringing it into contact with the incoming small coal. The mixture is broken to the size required for the smokeless fuel, and the latter then separated by screening. The small-sized material is a mixture of dried coal and smokeless fuel, and is charged into the retort. The installation produces 50 tons of smokeless fuel a day ("Colliery Engineering," September, 1927).

*Hird Process; British Carbonised Fuels, Ltd.*

The retorts are made of "cold blast-iron." The essential feature of the method is the introduction of vertical rod stirrers of suitable cross-section in a central position in the retort at 1-ft. centres; the number varying with the width of the retort. The stirrer is made to revolve slowly, and thus forms and maintains a central hole in the coal. This ensures a free passage for the products of carbonization up the centre of the coal and not against the walls of the retort. The main benefits are obvious, but an important result is that more rapid heat transfer is ensured from the walls of the retort to the centre of the coal. A unit is being erected by the Gas Light and Coke Company at the Richmond Gas-Works (J.S.C.I., 1928, 47, 30).

*Plassman Process; Leeds Fireclay Company, Ltd.*

In this plant the coal remains at rest during the whole period of carbonization, and the low-temperature coke is extracted by stripper plates at the end of 4 to 6 hours—*i.e.*, at the completion of the coking process. The central structure of the plant into which the coal is charged into coking chambers is enclosed by a shell which is arranged to revolve slowly, making a revolution in the time required to carbonize the coal. The fuel is compact and strong. A description of the results was given in the "Iron and Coal Trades Review" for March 11, 1927.

#### Mass Having Intermittent Movement.

*Fuel Research Plant.**

The retorts are constructed of grey cast iron, 21 ft. high, 6 ft. 6 in. by 7 in. widening to 6 ft. 10 in. by 11 in. The metal is 1 in. thick with strengthening ribs. The retort is worked at intervals of one, two, or three hours, according to the nature of the coal. The coke remains in a coke chamber until the next charging operation. Any type of coal can be dealt with, but grades below ⅜-in. mesh reduce the throughput. Each retort has a capacity of 3 to 4 tons per day. The unit at the Fuel Research Station has been in continuous operation for two years, and during the past year about 1500 tons have been treated under various research programmes. A plant to deal with 100 tons a day is being erected by the Gas Light and Coke Company at the Richmond Gas-Works.

#### Continuous Movement of Coal.

*Crozier Process; Mineral Oils Extraction, Ltd.*

The retort is of cast iron, and consists of two parallel walls 1 ft. 3 in. apart, 15 ft. high, and 5 ft. wide. Three enclosed flues pass through the retort at five levels. The system of working is a continuous one. One of the special features of the process is the fractional condensation of the volatile products. The unit installed is capable of carbonizing 10 tons of oil shale per day; but any coals which do not swell unduly can be treated.

#### Continuous Movement in Revolving Retort.

*Fusion Rotary Retort; Fusion Corporation, Ltd.*

The retorts are constructed of mild steel, and rotate in a horizontal position within a heated brickwork chamber. The retorts contain metal "breakers;" the type varying with the material to be carbonized. These "breakers" are free to revolve, and the effect is to turn over the material in the retort. Though as a rule the material leaves the retort as a powder, the author has seen products of considerable size. A large unit is in operation dealing with cannel coal.

#### Continuous Movement by Means of Ploughs.

*Freeman Multiple Retort; British Oil Conservation, Ltd., Willesden.*

The retort is 27 ft. high and 5 ft. in diameter, and consists of six cylindrical cast-iron chambers 18 in. deep placed vertically one above the other. A central shaft pierces the retort from top to bottom, and attached to it in each compartment is a circular plate which is rotated with the shaft. There are in each chamber two series of ploughs which serve to push the material across the tables and floors of the chambers and down through the retort. Each of the chambers is fitted with a separate offtake leading to a water-cooled condenser with a separate receiver tank attached. The coal enters at the top of the retort and gradually works its way through each of the chambers, and is discharged at the bottom in the form of small-sized semi-coke.

The plant tested, which has now been dismantled, was capable of carbonizing 6 tons of bituminous caking coal per 24 hours.

#### Movement in a Horizontal Channel Retort.

*Salermo System; Salermo, Ltd.*

The retort consists of a series of semi-circular channels placed at right angles to the path of the coal. The coal passes from one channel to the next, being ploughed by revolving arms. The product is in a fine state of division, and is discharged while hot into the grate of a furnace for combustion. There is a plant in this country to deal with 25 tons a day.

### Combined External and Internal Heating.

*"K.S.G." Process; Coal Oil Extraction, Ltd.*

The retort consists of an inner and outer cylinder, and is arranged to revolve slowly. The coal is fed into the lower end of the inner drum or cylinder, and is made to travel by means of a spiral. The material then falls on to the interior surface of the outer drum which is heated externally. Superheated steam can be admitted at several points. The smokeless fuel is dense and hard.

*Dvorkovitz System; Motor Fuel Proprietary, Ltd.*

According to reports which have appeared recently in the Technical Press ("Gas Journal," Jan. 18, 1928, p. 145), the carbonization is carried out by introducing neutral gas preheated to 200° to 400° C. to the top of the retort. The retort is also externally

* Fuel Research Technical Paper 17.

heated. The products are removed at the bottom of the retorts. After condensing out the tar, the gas is recirculated. The demonstration plant consists of two 5-ton retorts.

### DISTILLATION AND CARBONIZATION BY INTERNAL HEATING.

#### REVOLVING OR ROTARY RETORTS.

*" L. & N." Process; Sensible Heat Distillation, Ltd.*

In a résumé of seven years' work on the distillation of coal by the " L. & N." process, Mr. Nielsen (Bituminous Coal Congress, Pittsburg, November, 1926) states that distillation of coal can be effected in 2 to 2½ hours by means of hot gases. " It could be producer gas; blast furnace gas; water gas; combustion gases—in short, any gas not containing a perceptible percentage of free oxygen. The retort or kiln could be of the simplest imaginable construction—a slowly revolving, firebrick lined tube through one end of which the raw coal to be distilled enters, travelling in counter current with the hot gas entering the other and lower end. The rotation, in conjunction with the inclination, transports the coal forward continuously through the gradually increasing temperature zones." It is stated that " we avoid cracking the primary oil product, since the counter-current principle of distillation is employed." Furthermore, the large volume of gas employed lowers the vapour tension of the oils. The solid product is small in size, and is suitable for use in furnaces or for conversion into pulverized fuel or briquettes. At least one large unit is being erected in this country.

#### MOVEMENT IN A VERTICAL CHAMBER.

*Maclaurin Plant; Blair, Campbell, & McLean, Ltd.*

The producer unit broadly resembles a blast furnace in design, but is square. The height is 36 ft. and the internal dimension is 8 ft. at the widest point. The producer tapers upwards and downwards from this point. The coal is introduced at the top in 1-ton charges at hourly intervals, and requires 25 to 30 hours to pass through the retort. It reaches a zone at about 700° to 750° in 20 hours. The coke has frequently the appearance and form of the original coal, but is generally more open and cellular than the coal. The coke is cooled by steam. The plant at the Dalmarnock Gas-Works has a capacity of 100 tons a day, and has been in operation for some years.

*Midland Coal Products, Ltd.*

The retort consists of a cylinder tapering from 4 ft. 4 in. at the top to 5 ft. 6 in. at the widest point. The lower portion is an inverted cone 5 ft. long, water jacketed, and ending in a water-sealed discharge valve. The coal is converted into ovoid briquettes, using pitch as a binder; and these are charged into the retorts every 15 minutes. The carbonization is effected either by the combustion of some of the briquettes in each retort or by the hot gases from one of the retorts being delivered into the other retorts. Steam and air are passed into tuyères at the bottom. The coke in the form of briquettes is quenched and then screened. The capacity of the plant is 100 tons a day.

*Sutcliffe Process; Leigh Smokeless Fuels Company, Ltd.*

The coal is briquetted by pressure alone, and the briquettes are uniform in texture. The briquettes are charged at intervals into a vertical chamber. The carbonization is effected by means of superheated steam. The system of heating employed is by means of the alternate use of a regenerator. The fuel retains the original form of the briquette and is compact and extremely robust. A large unit has been erected at Leigh, Lancashire.

*Turner Process.*

The plant consists essentially of a superheater capable of delivering an adequate amount of low-pressure steam at a particularly high temperature to the bottom of a vertical metal retort. The retort is provided with means for charging and discharging. It is fitted with an outlet valve at the top arranged to open at a particular pressure, and not closed until the pressure has dropped to a determined lower pressure. The products of carbonization pass to a tubular condenser, where the steam and tar are condensed.

The coal is, in fact, treated with steam at alternating pressure; and this is stated to lead to a maximum yield of liquid distillate. A unit is in operation capable of dealing with 10 tons a day.

### GENERAL CONSIDERATIONS.

The data quoted in the paper have been extracted from the official tests carried out by the Director of Fuel Research where such information is available, or have been supplied by the firm themselves, and are included by their express permission. In certain cases the data in the firm's possession were not in the form suitable for inclusion in certain of the tables or could not be supplied in the time available.

Five plants have been tested by the Director of Fuel Research*—viz., (1) the Parker Plant, Low Temperature Carbonisation, Ltd.; (2) the Midland Coal Products, Ltd., plant; (3) the " Fusion " retort, Fusion Corporation, Ltd.; (4) the " Freeman Multiple " retort, British Oil and Fuel Conservation, Ltd.; (5) the Crozier retort, Mineral Oils Extraction, Ltd. (this report is in the press). The data quoted for the Maclaurin plant are the figures obtained for three months' working at the Dalmarnock Gas-Works. The details of the various processes not mentioned in the above list have been supplied by the firms.

The results obtained in the official tests are of great interest for a number of reasons. Everyone accustomed to carrying-out boiler trials and tests on plants, of which the performance is fairly uniform, will appreciate the difficulties in plants with such diverse characteristics as those tested. Thus, in one plant about 58,300 c.ft. of gas were obtained per ton of calorific value 193 B.Th.U. per c.ft., while in a second plant the volume was only 2740 c.ft. per ton of calorific value 1070 B.Th.U. per c.ft. The details of the tests are given in the official reports, but as would be expected the problems which caused the greatest difficulty were: (*a*) Obtaining average samples of the coal, and more especially of the coke; (*b*) the separation and measurement of the tar; (*c*) the accurate measurement of large volumes of gas; (*d*) the measurement of the actual temperature of carbonization. It was necessary in most cases to instal standardized instruments and apparatus. Samples of the products of adequate size were removed to the Fuel Research Station, where the detailed examination was carried out. In the carbonization of coal the effect of the conditions upon the properties and value of the products is so important that unless the whole of the products are measured and examined over an extended period, the yields of coke, tar, gas, and ammonia may be obtained under widely diverse conditions.

Table I. contains the analyses of the coals used in the plants.

The following is a brief description of the properties of the coals.

*Dalton Main Coal.*—Medium caking coal. The size in the case of the test in the Parker retort (Low-Temperature Carbonisation, Ltd.) was a washed breeze up to ½ in. In the Fuel Research plant, nuts, of which 35 to 43 p.ct. passed through ½-in. sq. mesh, were used.

*Kirkby Top Hard.*—Low caking properties. The drained washed slack was briquetted with about 8 p.ct. of pitch for the test in the Midland Coal Products plant. In the test on the Freeman plant washed slack was used.

*Welbeck Cannel.*—Run-of-mine cannel was used, containing some 10 p.ct. of bituminous coal which it was not economical to separate. The mixture yielded fairly compact coke in the assay test, the coke from the ground cannel was a coherent mass.

*Tullygarth Coal.*—This is a splint coal which does not swell unduly on carbonization. The coke produced in the assay was only just coherent; the Compredon-Gray value was 4.

For the Maclaurin plant, coals possessing caking indices between 8 and 16 are suitable, though coals with indices as high as 23 have been treated. The sizes preferred are treble nuts and upwards. The plant is not suitable for small coal and dross.

Leigh Smokeless Fuels, Ltd., can, by suitable blending of caking and non-caking coals, utilize a wide range of raw materials; the coal is briquetted by pressure alone prior to carbonization.

For the plant of the Illingworth Carbonisation, Ltd. the coal is brought to a particular condition by suitable preliminary treatment; and coals widely varying in properties may be used.

The percentages of solid residue obtained from the processes, together with the percentage of volatile matter present, are given in Table II.

The products from the plants, except the " Fusion " rotary retort, the Freeman " Multiple " retort, and the " Salermo " process, are in lump form, and are suitable for general domestic purposes. The amount of volatile matter present is only a broad indication of the ease with which the products will ignite; and with 4 p.ct. the product will ignite readily and yield

*Reports published by H.M. Stationery Office.

TABLE I.—*Analyses of Coal*

| Name of Retort . | Parker Process. | Midland Coal Products. | | Fusion Rotary. | Freeman Multiple. | Crozier Process. | Maclaurin Plant. | Leigh Smokeless Fuels, Ltd. | Illingworth Carbonisation, Ltd. | Coal Extraction, Ltd. | Salermo Process. | Fuel Research. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Name of Coal. . | Dalton Main. | Kirkby Top Hards. | Briquettes as Charged (from Washed Slack). | Welbeck Cannel. | Kirkby Top Hards. | Tully-garth. | — | Caking Suitably Blended. | Rough Slack Caking. | — | Durham. | Dalton Main. |
| Moisture . . | 2·4 | 9·6 | 14 5 | 1 8 | 9·4 | 11·4 (As charged wet weather) | 10·0 | *Nil* | 1·6 | 2·7 | 1·7 | 2·5 |
| Volatile matter *less* moisture. | 35·8 | 32·5 | 33·3 | 46·6 | 32·1 | 34·0 | 33·7 | 33·0 | 33·0 | 14·5 | 32·9 | 32·6 |
| Fixed carbon . | 57·2 | 52·6 | 47·1 | 36·8 | 51·6 | 44·2 | 50·7 | 62 5 | 54·0 | 78·3 | 60·4 | 58·5 |
| Ash . . . . | 4·6 | 5·3 | 5·1 | 14·8 | 6·9 | 10·4 | 5·6 | 4·5 | 11·4 | 4 5 | 5·0 | 6·4 |
| Caking index . | 19 | .. | .. | .. | .. | 4 | up to 16 | caking blends | caking coal | .. | caking | 16 |
| Ultimate analysis (dry coal)— | | | | | | | | | | | | |
| Ash . . . . | 4·75 | 5·94 | 5·97 | 15 00 | 7·73 | 11 77 | .. | .. | .. | .. | .. | 6·2 |
| Carbon . . . | 80·05 | 77·72 | 77·36 | 70·20 | 75·03 | 71·40 | .. | .. | .. | .. | .. | 80·1 |
| Hydrogen . . | 4·95 | 4·91 | 4·46 | 6·32 | 4·83 | 4·84 | .. | .. | .. | .. | .. | 5·0 |
| Sulphur . . | 1·10 | 0·96 | 1·21 | 0·78 | 1·56 | 0 80 | .. | .. | .. | .. | .. | 1·5 |
| Nitrogen . . | 1·60 | 1·94 | 1·47 | 1·50 | 1·36 | 1·58 | .. | .. | .. | .. | .. | 0·9 |
| Oxygen, &c. . | 7·40 | 8·53 | 9·53 | 6 20 | 9·49 | 9·61 | .. | .. | .. | .. | .. | 6 3 |

a good fire in the ordinary domestic grate. It is not necessary for the product to contain 8 to 10 p.ct. of volatile matter.

The product from the Parker plant (" Coalite ") was robust, contained only 4 p.ct. of volatile matter, and yielded a good hot fire in an ordinary domestic grate.

The product from the Midland Coal Products plant consisted of carbonized briquettes and portions of briquettes. It is quite suited for stoves as a substitute for anthracite, but was not so successful in the domestic grate.

The " Fusion " rotary retort gave a small-sized fuel which should be suitable for conversion into pulverized fuel.

The fuel from the Freeman " Multiple " retort was in powdered form of a highly combustible nature, and would be suitable for pulverizing or briquetting.

The coke or smokeless fuel from the Crozier retort gave a satisfactory fire, but not exactly smokeless, in a domestic grate. This was, however, due to the conditions prevailing during the test.

The fuel from the Maclaurin plant (Kincole) contains 3 to 4 p.ct. of volatile matter, but ignites quite readily. Maclaurin says that the ease of ignition is apparently due to the porosity of the fuel, and not to the volatile matter remaining in the coke. This conclusion of Maclaurin is supported by prolonged experience on a large scale, and is of great importance in relation to the suitability of cokes of all types for the domestic fire.

The fuel of the Illingworth Carbonisation process (" Ricoal ") is in compact lump form, and owing to the pre-treatment the texture and properties are uniform.

The product of Leigh Smokeless Fuels is in briquette form. Its density is from 1·00 to 1·10, but material up to 1·25 sp. gr. has been made. The hardness compares with foundry coke. It is used as a substitute for anthracite, and for domestic fires. Its high density is an advantage as a producer fuel and for steam vehicles.

The " Salermo " process yields a product of small size.

The solid residue from low-temperature carbonization forms some 70 p.ct. of the weight of the original coal, and the properties of the products must be closely examined in order that comparisons may be possible with other solid fuels. A systematic study of the relationship between the temperature of carbonization and the properties of the coke is required for each of the principles of carbonization, since the method used has a primary effect on the character of the product. Drakeley (" J.C.S.," 1922, 121, 22) examined the effect of the temperature of carbonization upon the chemical composition of the product, and found a rapid decrease in oxygen and hydrogen as the temperature of carbonization was increased.

Dr. Slater and Mr. H. Macpherson, in association with the author, have determined the normal moisture found in air-dried cokes produced at various temperatures. The specimens of cokes were made on a small scale, and after being ground were exposed to the air in a thin layer under standardized conditions, and the percentage of moisture present was then determined by the ordinary method.

TABLE III.

| Temperatures of Carbonization. | Moisture in Coke after being Exposed to Air, P.Ct. | |
|---|---|---|
| | Coal A. | Coal B. |
| 300 . . . . . | 0·8 | 1·5 |
| 400 . . . . . | 0·9 | 1·4 |
| 500 . . . . . | 1·8 | 2·4 |
| 600 . . . . . | 2·8 | 3·5 |
| 700 . . . . . | 3·5 | 4·6 |
| 800 . . . . . | 4·2 | 4·4 |
| 900 . . . . . | 3·0 | 2·6 |
| Original coal . . . . | 1·5 | 1·6 |

The amount of moisture present in the cokes after exposure to the air appears to be a function of the temperature of carbonization of the coal, the percentage present is relatively low, from 400° to 600° C., and attains a maximum at about 700° to 800° C., for the seams examined. The percentage of moisture in the coke may, in fact, be used as a rough indication of the temperature at which the coal was carbonized.

The calorific value of the coke from certain coal seams may be higher than that of the original coal, as is seen from the results in Table IV. (test of Freeman " Multiple " retort (*loc. cit.*) ).

The values were obtained from large-scale tests, and the difficulties of obtaining accurate samples must be taken into consideration.

Cokes possessing a high calorific value may be superior to the coals from which they were prepared, since, for any given excess air, the theoretical temperature of the products of combustion will be greater (Nielsen, " GAS JOURNAL," Feb. 2, 1927). This will be advantageous from certain points of view, but it

TABLE II.—*Carbonized Residue.*

| — | Parker Plant. | Midland Coal Products. | Fusion Rotary. | Freeman Multiple Retort. | Crozier Retort. | Maclaurin Plant. | Leigh Smokeless Fuels. | Illingworth Carbonisation, Ltd. | Salermo Process. | Fuel Research Retort. |
|---|---|---|---|---|---|---|---|---|---|---|
| Cwt. per ton . . . . | 13·9 | 7·5 | 11·7 | 13·3 | 15·4 | 9·9 | 14·0 | 15·2 | 15·2 | 15·1 |
| Volatile matter, p.ct. . | 4 0 | 2·0 | 9·7 | 15·2 | 14·6 | 4 to 6 | 4·5 | 5 to 6 | 9·0 | 6 8 |
| Breeze through ½-in. sq. mesh . . . . . | 4·6 | 15·0 | 99·6 | 59·3 | 17·4 | about 16·0 | *Nil* | 5·3 | 64·8 | 17·2 |
| Temperature of carbonization, ° C. . . . . | 550–850 | up to 1200 | 550 | 500 | up to 770–820 | .. | .. | 600 | 450 | 625 |

TABLE IV.—*Calorific Value of Coals and Low-Temperature Cokes.*

| Coal. | Temperature °C. | Coal. | | | L.T. Coke. | |
|---|---|---|---|---|---|---|
| | | Moisture. | Ash. | Calorific Value B.Th.U. per Lb. | Moisture. | Calorific Value B.Th.U. per Lb. |
| Dalton Main | 600–800 | 5·4 | 4·7 | 12,950 | 4·2 | 13,250 |
| Kirkby Top Hards— | | | | | | |
| Test 1 | 566 | 9·2 | 6·4 | 12,050 | 3·7 | 12,048 |
| ,, 2 | 500 | 9·4 | 6·9 | 11,970 | 2·4 | 12,200 |
| ,, 3 | 488 | 9·3 | 5 7 | 12,190 | 2·6 | 11,961 |
| ,, 4 | 500 | 9·6 | 17 4 | 10,390 | 2·2 | 10,747 |
| Brynna | 500 | 3·9 | 4·5 | 13,430 | 1·8 | 13,140 |

might be objectionable where the coal ash melts at a critical temperature.

In tests which have been carried out to determine the reactivity of low-temperature coke, it has been found to be more active to carbon dioxide than gas or metallurgical coke. High reactivity may be a cause of inefficiency in fuel, especially for use in closed stoves. If rapid reduction of carbon dioxide occurs, loss may be occasioned owing to carbon monoxide escaping, if the regulation of the draught is difficult. Viewed from this aspect, high-temperature coke, in fact, posseses distinct advantages, particularly when it is dry and has been carefully graded. The combustibility of lump low-temperature coke is of interest, as upon it depends the ease with which a fire can be made from the product. It has been found that low-temperature coke containing between 4 and 6 p.ct. of volatile matter can be easily lighted by means of ordinary wood and paper, and some fifty experimental fires were started and a good fire obtained in every case in under six minutes. The ease of ignition of low-temperature coke is one of the most important factors for domestic purposes; but this must be associated with the production of fire which burns brightly and relatively uniformly. It has been shown by Dr. Fishenden that various samples of low-temperature cokes, burning in different types of open grates, emit into the room up to 34 p.ct. of their total thermal energy as radiant heat compared with up to 25 p.ct. from coal fires. Bligh and Hodsman ("The Behaviour of Carbonized Fuels in the Open Fire-Grate," Chem. and Ind., March 11, 1927), have shown that the radiation efficiency of a coke depends upon its ash content. For instance, two cokes, both nearly dry, with ash contents 1½ p.ct. and 5½ p.ct. respectively, gave in an open grate 29 and 25 p.ct. radiation efficiency, compared with 20 p.ct. for coal. By treating coke with sodium carbonate, its ignitibility and combustibility were greatly increased, although the radiation efficiency was slightly decreased.

For water heating in back boilers and small independent boilers, low-temperature coke gave efficiencies varying from 14½ to 42 p.ct. It is not necessary to point out the advantages of either gas, coke or low-temperature coke from the point of view of the cleanliness of the grate, the chimney, and the general atmosphere.

Where there is no increase in the size-value of the solid product and the semi-coke is in a fine state of division, it will have to compete directly with the coal from which it is produced.

The utilization of the coke as pulverized fuel has received considerable attention, and according to Dunn, "Pulverized and Colloidal Fuel" (Ernest Benn, Ltd.), Messrs. Edgar Allen & Co. carried out experiments in a reheating furnace with pulverized "Coalite" ground in their own turbo-pulverizer. The normal forging temperature was 1000° to 1200° C., but as an experiment the temperature of the furnace was raised to 1400° C. They remark that the low percentage of moisture makes the fuel suitable for pulverizing, while the work of cleaning the flues of the furnace was reduced.

According to Nielsen ("GAS JOURNAL," 1927, 177, p. 254), tests on a large scale show that powdered semi-coke of the "L & N" type has improved the usual steaming conditions; and Captain Brand, R.A.N. (Institution of Naval Architects, 1927, July 12) described tests carried out upon "L & N" fuel from a Leicester coal by Messrs. Clarke, Chapman, & Co., Ltd., the efficiency quoted being 67·4 p.ct. I am informed by Mr. Woodeson, of Messrs. Clarke, Chapman, & Co., Ltd., that so long as the temperature of the furnace is maintained above (say) 1000° C., no difficulty whatever is experienced in the combustion of semi-coke as pulverized fuel; but below this temperature, should the volatile content be low, the flame may be extinguished. No difference has been experienced in the behaviour of the ash of semi-coke as compared with that of coal in the furnace. The wear and tear of the pulverizer was somewhat increased, but the product obtained tends to be of a more uniform grade, but at the same time slightly coarser than the coal. In view of the above, it is clear that the utilization of low-temperature coke in the pulverized form offers a promising field for industrial and scientific investigation.

A promising outlet for low-temperature coke would appear to be for use in gas producers for motor traction. Great progress is being made on the Continent in the development of gas producers burning charcoal, and there appears every reason to hope that low-temperature coke of suitable properties and size could be utilized in similar producers. Such a method of utilization would help to make this country less dependent on outside supplies for its motor fuels. Low-temperature coke has been found to be an excellent fuel for steam lorries.

The chief disadvantage of low-temperature coke compared with coal lies in its low bulk density. Broadly speaking, it may be assumed that the lump fuel occupies roughly twice the volume of coal. In view of this the cost of transport will be greater. This does not apply to the pulverized material, since the bulk density of the coke and coal of similar degrees of fineness would probably be of the same order.

The constitution of the tars produced by the various methods of carbonization has not been explored in sufficient detail to establish with accuracy the relationship of the composition of the tar to the method of carbonization employed. The actual broad groups of compounds contained in the tars can be distinguished fairly easily, but the constituents of the groups cannot be determined accurately. There is no doubt that the tars produced under various conditions differ in composition, but it has not been established whether the fluctuations are due to variations in the proportions of some common constituents present in each tar, or to fundamental differences in the compounds present. As one example, in Table VII. it will be seen that the saturated hydrocarbons fall from 29·8 p.ct. in the distilled oil made at 400° C. to 6·2 p.ct. in the distilled oil made at 700° C.

The question of the constitution of the tars requires an exhaustive examination in order to designate more accurately the influence of the method of carbonization upon the possible commercial outlets for the tars. A close examination of the values contained in Table V. suggests differences in the composition due to the method of carbonization adopted, apart from that due to the different types of coal. In the methods of internal heating the hot gases are produced by combustion of part of the fuel or of producer gas; and it may be of use to consider the effect of the presence of oxygen in the gases upon the properties of the coal, and the possible influence upon the composition of the tars. Parr and Hadley ("Univ. Ill. Bull.," 1914, No. 76), have shown that oxidation of coal not only leads to the modification and destruction of the caking properties, but that such oxidation has a profound effect upon the chemical constitution of the coal substance. This subject is being exhaustively investigated by Wheeler and his colleagues, Tideswell and Francis. Francis and Wheeler ("J.C.S.," 1927, 128, 2958) state that unstable oxygenated groups are formed which are ultimately carboxylic in character. Travers (Institute of Fuel) has stated that about 60,000 c.ft. of water gas are required if the source of heat is to be the sensible heat of the gases. If such gas contains oxygen, and comes into contact with the coal in the cooler zones of the retort, an oxidized product ("thermodized," according to Wisner*) will be formed which later will undergo carbonization in the hotter portions of the system. The whole problem is being studied on a semi-large scale by Prof. Wheeler, who has found it possible so to control the degree of oxi-

* C. B. Wisner, "The Missing Link in Low-Temperature Carbonization" (Bituminous Coal Congress, Pittsburg, November, 1926).

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TABLE V.—*Yield and Composition of the Tars.*

| Name of Retort | Parker. | Midland Coal Products. Pitch Briquettes | Fusion Rotary. Cannel. | Freeman Multiple (Test 3). | Crozier Retort. | Maclaurin Plant. | Leigh Smokeless Fuels. | Illingworth Carbonization, Ltd. | Coal Extraction, Ltd. K.S.G. | Salermo Process. | Fuel Research. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Yield of tar, gallons per ton | 18·6 | 21·0 | 50·2 | 21·1 | { 16·4 / 2·4 } | 20·4 (wet) | 20·0 | 17 | .. | 20·3 | 17·3 |
| Specific gravity | 1·063 | 1·076 | .. | 1·057 | 1·028 | 1·032 | 1·027 | 1·07 | 1·053 | 1·023 | 1·050 |
| Spirit from gas, gallons per ton | 1·78 | .. | 3·7 | 0·85 | 0·80 | .. typical tar | .. | 3·5 | .. | .. | 1·4 |
| Water | .. | .. | .. | .. | .. | 1·70 | 1·5 | .. | .. | .. | .. |
| Up to 120° C. | .. | .. | .. | .. | .. | 0·64 | .. | .. | .. | .. | .. |
| Up to 170° | 4·7 | 1·1 | .. | 6·9 | 4·1 | .. | 9·5 | .. | 6·1 | 7·0 | 3·4 |
| 120°–230° | .. | .. | .. | .. | .. | 5·47 | .. | .. | .. | .. | .. |
| 170°–230° | 14·9 | 3·9 | .. | 9·5 | 11·7 | .. | 1·0 | .. | 17·2 | 19·9 | 14·7 |
| 230°–270° | 12·9 | 4·1 | .. | 13·9 | 11·9 | 14·14 | 7·0 | .. | 12·9 | 12·4 | 11·1 |
| 270°–300° | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 270°–310° | 18·1 | .. | .. | .. | .. | .. | 13·0 | .. | .. | 11·2 | .. |
| 270°–330° | .. | .. | .. | .. | 15·7 | .. | .. | .. | .. | .. | .. |
| 270°–345° | .. | .. | .. | .. | .. | 26·04 | .. | .. | .. | .. | 23·4 |
| 270°–360° | .. | 26·9 | .. | 29·8 | .. | .. | .. | .. | 23·0 | .. | .. |
| 300°–350° | .. | .. | .. | .. | .. | .. | 45·0 | .. | .. | .. | .. |
| Pitch | 48·4 | 63·2 | .. | 39·3 | 55·9 | 48·50 | 23·0 | .. | 40·7 | 48·7 | 45·8 |
| Loss | 1·0 | 0·8 | .. | 0·6 | 0·7 | 3·51 | .. | .. | .. | 0·8 | 1·6 |
| Tar acids | 17·0 | 13·4 | .. | 24·5 | 14·3 | .. | .. | .. | 25·5 | .. | .. |

dation of coal during pre-heating as to obtain from a coking coal during subsequent carbonization a semi-coke of any required degree of agglomeration. The oil yield is not materially affected by such slight oxidation as is sufficient to prevent agglomeration of the coke; but (with the particular coal treated) the phenol-content of the tar decreases.

If large volumes of gas are used or are produced, the complete condensation of the tar and especially the recovery of the light motor spirit from the gas becomes more difficult. Whatever the method of carbonization, certain generalizations are possible; and it is now accepted that tar made below 600° C. contains only small proportions of benzene and its homologues. It has been found that at temperatures about 600° C. appreciable quantities of toluene are produced, although the benzene is still small. Naphthalene is absent below 600° C. from low-temperature tars; but methyl-naphthalenes and methyl-anthracenes are present. The three main groups of compounds present in low-temperature tar are:

Hydrocarbons or neutral oils. This group contains such series of compounds as the paraffins, olefines, naphthenes, unsaturated polymethylenes, &c. The proportions of the various series of hydrocarbons have not been determined with accuracy, largely owing to the absence of suitable methods. In Table VII. the percentages of saturated hydrocarbons are given for a number of tars. Parrish and Rowe (J.S.C.I., 1926, 45, 99T), working on a tar prepared by external heating, found 1·5 p.ct. of sulphur in the hydrocarbon oil separated from a tar which contained 1·3 p.ct. of sulphur.

The second main group consists of phenolic compounds; and these in the main resemble the bodies found in high-temperature tar. In certain aspects, however, the phenolic bodies present in low-temperature tar are of particular interest. The work of Edwards (J.S.C.I., 1924, 43, 143) is outstanding, in that he identified two main classes of phenolic compounds. The first is composed of phenols and its homologues; and the second is a group complex in constitution, which he designated rhetinols. The rhetinols form from 9 to 15 p.ct. of the tar from externally-heated processes. The phenolic substances were analyzed by (1) Brittain, Rowe, and the author ("Fuel," 1925, 4, 263, *et seq.*), and (2) Parrish and Row (*loc. cit.*), with the following results.

TABLE VI.

| — | P.Ct. by Weight. | |
|---|---|---|
| | (1.) | (2.) |
| Resin acids (rhetinols) | 10·9 | 15·5 |
| Phenol | 0·2 | 0·7 |
| O. cresol | 2·3 | 6·8 |
| M. cresol | 2·9 | |
| Xylenols | 4·7 | 6·1 |
| Higher phenols | 8·7 | 4·7 |

The third group of compounds are the basic substances.

The proportion of basic compounds found in tar as distinct from ammonia varies from 2 to 4 p.ct. The constitution of the group of compounds is being studied for one type of tar. Although the amount is small, some significance is attached to their presence, since they are stated to have a deleterious influence upon any oils which might be used as high-class lubricants. The bases form dark coloured viscous oils soluble in organic solvents. The following compounds have been detected: Di- and tri-ethylamine, pyridine, methyl- and dimethyl-pyridine, quinoline, methylquinoline.

The influence of the temperature of carbonization upon the composition of the tar produced by external heating under certain prescribed conditions was described by King, Linnell, and the author (J.S.C.I., 1926, XLV., 47, 385); and Table VII. contains the chief values.

TABLE VII.

| Temperature of Carbonization, ° C. | 400. | 500. | 550. | 600. | 700. |
|---|---|---|---|---|---|
| Yield of tar, galls. per ton | 9·1 | 16·0 | 17·6 | 16·4 | 12·9 |
| Sp. gr. of tar | 0·958 | 0·986 | 1·015 | 1·039 | 1·080 |
| Fractions, p.ct. by weight of tar— | | | | | |
| 0–172 | 10·6 | 9·0 | 6·0 | 6·4 | 6·0 |
| 172–234 | 26·1 | 22·4 | 15·8 | 16·7 | 15·6 |
| 234–277 | 14·3 | 12·7 | 14·4 | 13·4 | 11·1 |
| 277 to pitch | 25·7 | 28·4 | 30·6 | 27·5 | 15·1 |
| Pitch | 22·2 | 27·4 | 33·4 | 34·6 | 52·1 |
| Phenols in oils (*i.e.*, tar less pitch) | 24·5 | 29·2 | 29·3 | 32·9 | 35·9 |
| P.ct. saturated hydrocarbons in distilled oil | 29·8 | 22·9 | 18·5 | 13·4 | 6·2 |

In the test on the Freeman "Multiple" retort, an examination was made of the tar collected from each of the separate chambers. The coal passes downwards from one chamber to the next lower, and is ploughed and turned over in the process. The chambers are maintained at a definite temperature (Table VIII., column 2), and each is fitted with a separate outlet for the removal of the tar. The tar produced is not, in fact, exposed to any higher temperature than that of the chamber in which it is produced. The results are collected in Table VIII.; and it is seen that the specimens of tar are changing in general composition, while the particular coal (the Top Hard Seam) evolves a considerable proportion of tar above 450° C. There is a gradual increase in the phenolic bodies as the temperature rises, accompanied by a decrease in the calorific value of the tar.

The problem of the utilization of low-temperature tar cannot be dissociated from the tar distillation industry and the relationships established between that industry and the coal gas industry. In this connection, reference may be made to the valuable article by T. F. E. Rhead in "Britain's Fuel Problems" ("Fuel Economist"), in which the co-operative schemes between coal gas undertakings and tar distillers are discussed. In this method of dealing with tar, an agreed minimum price is paid, *plus* any additional profit on an agreed schedule. Already some 60,000,000 to 70,000,000 gallons per annum are dealt with on this principle. The object is obviously a desirable one—viz., to economize in the treatment of the tars and to establish a uniform market.

A further important fact which requires considerable emphasis is that in vertical retorts tar is evolved from the coal at low temperatures for a considerable period before the coal is exposed to the high temperature in

TABLE VIII.—*Total Yield of Tar, 20·6 Galls. per Ton Dry Coal.*

| Chamber. | Temperature of Chamber, °C. | Galls., Tar. | Sp. Gr., Tar. | Calorific Value, B.Th.U. | Fractions. | | | | Pitch. | Tar Acids, Galls. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 0 to 170. | 170 to 230. | 230 to 270. | 270 to 360. | | |
| 1 | 102 | 0·52 | 0·967 | 17,390 | 10·1 | 10·8 | 22·6 | 33·1 | 22·8 | 0·09 |
| 2 | 220 | | | | | | | | | |
| 3 | 326 | 1·58 | 1·014 | 16,985 | 7·5 | 9·1 | 15·6 | 42·5 | 24·0 | 0·42 |
| 4 | 415 | 4·88 | 1·049 | 16,380 | 5·1 | 6·4 | 14·1 | 33·6 | 39·8 | 1·27 |
| 5 | 457 | 4·66 | 1·047 | 16,340 | 5·5 | 7·6 | 15·9 | 28·1 | 41·9 | 1·20 |
| 6 | 500 | 6·64 | 1·059 | 16,350 | 5·6 | 7·9 | 16·0 | 29·8 | 39·7 | 1·58 |
| Air-cooled condenser. | .. | 1·3 | 1·013 | 16,730 | 15·4 | 10·6 | 14·0 | 30·3 | 28·9 | 0·34 |

the lower part of the retorts. Where steaming is practised—and this may amount to 20 p.ct.—the products are "protected." The general result is that vertical retort tar differs in composition from horizontal retort tar, and is allied in many respects with low-temperature tar. One example may be cited (E. G. Stewart, Trans. Lond. and Dist. Jr. Gas Assoc., 1911, p. 43), in the relative amounts of "free carbon" in the pitch obtained from various tars:

Gas tar (horizontal retorts at 1300° C.) contained 36 p.ct.
Vertical retort tar (1260° C.) contained . . 5·5 ,,
Low-temperature tar contained . . . . . 2 ,,

It is also well known that in high-temperature vertical retorts high yields of tar can be obtained; and in experiments at the Fuel Research Station using double nuts (Dalton Main), over 18 gallons per ton have been recorded. The coal treated in vertical retorts in the gas-works of the country is about 50 p.ct. of the total carbonized; and the amount is increasing.

The light motor fuel obtained by the distillation of low-temperature tar, or by scrubbing the gas, is one of the valuable products. Compounds are present which lead to darkening of the colour; but these can be eliminated by suitable treatment. The product is then colourless, and may be preserved indefinitely without deterioration. It is an excellent motor fuel, and, as shown by experiments at the Fuel Research Station, possesses the advantage of not developing "knocking" or "pinking" under high compressions.

The idea of obtaining lubricating oils from coal tar is important, but not new; and "heavy oil" from coal tar has been largely used as a lubricant. The absence of naphthalene from low-temperature tar suggests that the oils would be superior to those from ordinary coal tar, although Lunge considers the lubricants from coal tar inferior to those from petroleum. Nielsen and Baker ("Mechanical Engineering," 1927, 49, 1109) state that lubricating oil produced from tar made from bastard cannel coal by the "L & N" process is superior to straight mineral oil. The refining process consisted, in the first instance, of ordinary distillation yielding the following fractions: 0°-300° C., 16·5 p.ct.; 300°-350°, 13·6 p.ct.; 350°-370°, 9·8 p.ct.; above 370°, 41·7 p.ct.; pitch, 7 p.ct.; water and loss, 12·5 p.ct. The fraction above 370° was worked-up for lubricating oils by removing the tar acids (20 p.ct. by volume) with caustic soda, and then treatment with 3 p.ct. sulphuric acid, by which means the oil was reduced to 70 p.ct. of the original volume. The refined oil was distilled, and the first 25 p.ct. returned to the kerosene fraction. The remainder was passed through a filter press at −5° C., to remove paraffin wax. The wax-free oil was fractionally distilled; and the grades of lubricants amounted to 15 p.ct. of the original crude oil. The oil from the "Leigh" smokeless fuel plant, distilling between 320° and 400° in steam, gave promising indications of being suitable for lubricating oil.

It would be interesting to have information of the amount of lubricating oil a number of typical bituminous coals would yield when carbonized by various processes, and the approximate cost of refining the oils. The relative prices of lubricating oil and crude oil per gallon were in 1923, 13·85d. and 3·77d.; 1924, 13·84d. and 4d.; 1925, 13·42d. and 3·73d.; 1926, 12·20d. and 3·65d.; 1927, 11·2d. and 3·47d.

Prof. Morgan has informed the author that the application of solvent methods of separation at the Chemical Research Laboratory has increased the recovery of paraffin wax; and the waxes thus become an important product of the tar. A series of waxes has been obtained. A further avenue is the exploration of the lubricating properties of certain fractions and the investigation of the complex aromatic hydrocarbons. Prof. Morgan and Dr. Pratt have previously stated that β-methyl anthracene is present; and now alkylated anthracenes and allied compounds are being separated.

The phenolic compounds offer a wide field for investigation. The phenolic portion of low-temperature tar, as pointed out by Edwards (*loc. cit.*) forms, with caustic soda, a solution which froths strongly on agitation; and this property is associated largely with the rhetinols. The phenols, as distinct from the rhetinols, contain a large proportion of compounds higher in boiling-point than xylenols, and have been found to possess a high germicidal coefficient. It has been suggested that cresols could be more widely applied in agriculture for soil sterilization; and in leaflet No. 209 of the Ministry of Agriculture and Fisheries, a comparison is made of the efficiency of various methods. Although it is shown that sterilization by steam is the most effective method, cresylic acid possesses certain minor advantages. It would appear that the combined effect of the rhetinols and higher phenols would be worthy of study.

Prof. Morgan, at the Chemical Research Laboratory, is exploring the methods for the removal of the substances causing discoloration of the phenols. The various fractions of the phenols are being examined for germicidal action, together with their chlor derivatives; and certain fractions have been proved to possess considerable bactericidal potency. Good hardening synthetic resins have been obtained by condensations with formaldehyde.

The presence of only a small proportion of benzene and its homologues in low-temperature tar leaves an important industrial field to be filled by high-temperature tar. It is essential for our coal tar dye, chemical, and explosive industries that large quantities of benzene and its homologues should be available. The hydrocarbon fractions of low-temperature tar should find applications as solvents in chemical industry. The phenolic fractions would compete directly with the same fractions derived from high-temperature tar, and be used for creosoting timber and in the manufacture of insecticides, disinfectants, &c. The pitch and higher fractions appear to the author to offer a promising field for research.

If low-temperature tar is produced in such quantities that a portion has to be used as fuel oil, it will enter into competition with crude petroleum oil, the import price for which in the last five years is given above. In the purchase of such oils, the basis for evaluation is that of the calorific value; and the following figures show average values for petroleum and tar products:

| — | B.Th.U. per Lb. (Gross). |
|---|---|
| Crude petroleum | 18,600 to 19,600 |
| Fuel oil, "heavy" | 18,600 ,, 20,000 |
| ,, ,, "Diesel" | 19,200 ,, 20,000 |
| High-temperature gas tar | about 16,000 |
| Low-temperature tar | 15,500 to 16,500 |

The crude tars from low-temperature carbonization, in common with those from high-temperature carbonization, are not miscible with petroleum oils in all proportions. Although this disadvantage may be serious for marine purposes when the amount of low-temperature tar available is small in relation to the petroleum products, it would not be so serious if sufficient tar were produced to allow of depôts being supplied from home sources. In this case, the chief difficulty would be that a vessel leaving this country using low-temperature tar as fuel oil, and finding it necessary to take in supplies of petroleum fuel oil, would have to ensure the complete removal of the tar fuel from its oil bunkers and pipelines before doing so.

When petroleum fuel oil is added to low-temperature tar, a deposit is formed. This deposit separates slowly, and may be a soft plastic or a hard pitch. The tars can be used as fuels for Diesel engines.

In a previous paper (J.S.C.I., 1925, XLIV., 413), an examination of the statistics was made, and showed that the price realized for high-temperature tar ranged from 3d. to 10d. per gallon, according to local conditions. During 1926, 4·6d. per gallon was

TABLE IX.—*Gas.*

| Name of Process | Parker Process. | Midland Coal Products. | Fusion Rotary. | Freeman Multiple. | Maclaurin Plant. | Leigh Smokeless Fuel. | Illingworth Process. | Coal Oil Extraction, Ltd. K.S.G. | Salermo Process. | Fuel Research. |
|---|---|---|---|---|---|---|---|---|---|---|
| Volume of gas, c.ft. per ton | 5620 | 58,300 | 2740 | 1720 | 33,849 | 10,000 | 6200 | 3505 | 3920 | 5188 |
| Calorific value, B.Th.U. per c.ft. | 700 | 193 | 1070 | 895 | 239·5 | 350 | 780 | 814 | 870 | 719 |
| Therms | 39·6 | 112·5 | 29·3 | 16·1 | 81·1 | 35 | 48·4 | 28·5 | 34·1 | 37·3 |
| $CO_2$ | 4·0 | 1·6 | 6·5 | 10·2 | 7·0 | .. | .. | 4·5 | .. | 4·0 |
| $C_nH_m$ | 4·3 | .. | 13·2 | 5·4 | 0·4 | .. | .. | 5·2 | .. | 3·4 |
| $O_2$ | 1·0 | *Nil* | 1·0 | 1·4 | 0·4 | .. | .. | 1·6 | .. | 1·0 |
| CO | 6·1 | 28·1 | 6·4 | 6·7 | 12·2 | .. | .. | 5·9 | .. | 6·6 |
| $H_2$ | 37·2 | 16·6 | 17·1 | 9·1 | 20·2 | .. | .. | 15·0 | .. | 31·3 |
| $C_nH_{2n+2}$ | 39·6 | 4·4 | 49·5 | 50·4 | 12·9 | .. | .. | 53·0 | .. | 42·6 |
| $N_2$ | 7·8 | 49·3 | 6·3 | 16·8 | 46·9 | .. | .. | 14·8 | .. | 10·6 |
| "*n*" | 1·23 | .. | 1·59 | 1·4 (about) | .. | .. | .. | .. | .. | 1·27 |

realized by the chief London gas-works, while only 3d. per gallon could be obtained in certain parts of the provinces. The amount of coal tar made in Great Britain in 1926 was about 187 million gallons, or some 9 gallons per ton of coal; while the pitch produced was 310,412 tons. The "Gas World" (Dec. 31, 1927), in their interesting annual review, consider £3 per ton is a reasonable price for tar, which is equivalent to about 3s. per ton of coal carbonized. The low price of tar is due to the fact that remunerative prices can be realized for gas and coke. One of the most valuable products from tar is the pitch; and here the competition from bitumen for road preparations and other purposes is becoming intense. The pitch from low-temperature distillation differs greatly from ordinary pitch; and new uses must be sought for it. It has proved suitable for briquette making.

It will be observed from a study of the values in Table IX. that, from the point of view of the gas produced, the processes may be separated into two groups. On the one hand, the gas obtained from externally-heated retorts may have a high calorific value; while in internally-heated retorts a large volume of gas of low calorific value may be produced, unless some system of re-circulation is adopted. The gas of high calorific value, and incidentally of high illuminating value, is of some interest as a means of enriching ordinary town gas, but obviously is not of primary interest to the coal gas industry, which can meet all the modern demands by other methods of gas making. The gas may find special uses in industry, since it is not greatly inferior to the gas produced by the cracking of oils.

The percentage of unsaturated hydrocarbons in the gas is relatively high; and recently Manning, King, and the author (Fuel Research Technical Paper No. 19 in the press) have determined the proportions of ethylene, propylene, and butylene present in a special series of gases. Table X. contains some of the results from an externally-heated system, together with the values from horizontal retort gas for comparison.

TABLE X.

| Temperature of Carbonization. °C. | Total $C_nH_m$ in Gas. | Olefines Present. | Ratio—Ethylene : Propylene : Butylene. |
|---|---|---|---|
| 400 | 5·0 | 2·25 | 31·5 : 42·2 : 26·3 |
| 500 | 3·9 | 2·26 | 32·5 : 39·5 : 28·0 |
| 600 | 5·6 | 3·63 | 48·6 : 25·0 : 26·4 |
| 700 | 5·3 | 3·93 | 65·1 : 25·0 : 9·9 |
| Horizontal 1350 retorts | 2·9 | 2·26 | 83·9 : 12·3 : 3·8 |

Many suggestions have been advanced for the utilization of the gas from externally-heated retorts based either upon its high calorific value or upon the recovery of (or products from) the unsaturated and saturated hydrocarbons. It is possible by compressing the gas to condense a proportion of the unsaturated and of the saturated hydrocarbons; and this product can be employed as a substitute for acetylene for welding purposes[1]. It possesses the advantage of being perfectly safe when stored in cylinders. It would appear that the unsaturated hydrocarbons might be recovered as alcohols; but it seems more attractive to convert them into glycols, and thus obtain products having special uses as solvents, anti-freeze compounds, and as substitutes for glycerine[2]. It has been found that the nitrated unsaturated hydrocarbons can be used as explosives[3]. If it is found that lead tetraethyl is a desirable addition to motor fuels, large quantities of ethylene dibromide will be required to counteract some of the effects of the lead compounds, and coal gas from high or low temperature processes would be a source of supply. A rather strange use has been found for ethylene—viz., for ripening and colouring citrus fruits (Chace and Denny, Ind. Eng. Chem., 1924, 16, 339). The question of the utilization of large volumes of gases of low calorific value is of great industrial interest. It is generally known that Mr. Helps, of the Nuneaton Gas-Works, has for many years advocated the more general adoption of gas of low calorific value for domestic and industrial purposes, on the grounds of increased efficiency. Gases of the type produced in the Maclaurin plant and Midland Coal Products plant would be substantially of a suitable calorific value. Such gases are eminently suitable for most industrial purposes, and opinions are not unanimous as to the relative efficiencies of such gases and those possessing a calorific value of about 450 to 500 B.Th.U. per c.ft.

The problem of the treatment of the aqueous distillate from the low-temperature carbonization of coal is a pressing one. Plants in which an inconsiderable amount of water or steam is brought into contact with the gases have advantages in that the volume of liquor to be treated will be small. Viewed from the standpoint of the production of ammonium sulphate, it must be admitted that the aqueous distillate is practically worthless except in the case of the Maclaurin plant and the "Leigh" smokeless fuel plant—in fact, according to the "Gas World" (*loc. cit.*), "ammoniacal liquor as a revenue-earning constituent of gas manufacture has almost disappeared." The total volume of liquor produced will vary with the process; and its composition will depend upon the method of carbonization. Generally speaking, however, low-temperature aqueous distillates contain about one-half the ammonia found in horizontal gas liquor.

Table XI. gives the values for the undiluted aqueous distillate produced at temperatures from 400° to 700° C. (King, Linnell, and the author, *loc. cit.*)

TABLE XI.—*Composition of Liquors.*

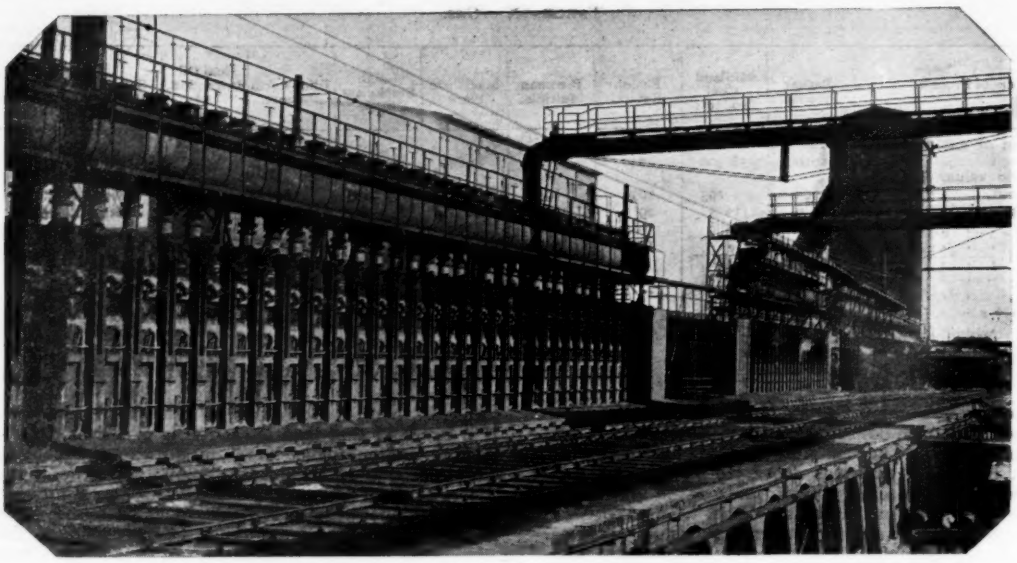
| Carbonizing Temperature | 400°. | 500°. | 550°. | 660°. | 700°. |
|---|---|---|---|---|---|
| Reaction | Acid. | Acid. | Neut. | Alk. | Alk. |
| Acidity (HCl, grammes per litre) | 1·05 | 0·09 | .. | .. | .. |
| Sp. gr., at 15° | 1·003 | 1·006 | 1·009 | 1·009 | 1·016 |
| Fe, grammes per litre | 0·44 | 0·37 | 0·24 | 0·28 | 0·15 |
| Cl, grammes per litre | 2·61 | 9·72 | 12·86 | 18·41 | 15·24 |
| $NH_3$, grammes per litre | 1·24 | 3·23 | 6·61 | 12·06 | 15·68 |

As far as is known, a comprehensive study of the aqueous distillate produced from various low-temperature processes has not been published. Information is required upon the proportion and constitution of the sulphur and other compounds present in the various liquors produced from the plants undergoing development. It is obviously impossible to run such liquors into streams or sewers unless special arrangements are made; and means must be discovered to render them innocuous. The problem is at present engaging the attention of the Institution of Gas

[1] Gasol. Hock, Z. angew. Chem., 1925, **38**, 945.

[2] Preparation of glycols, &c. Brooks, Chem. and Met. Eng., 1920, **22**, 629.

[3] Explosives. U.S.P., 1,485,003, Feb. 26, 1924.



65 Kogag regenerative ovens, Emscher

# GIBBONS "KOGAG" COKE OVENS

| | CONSTRUCTION IMPROVEMENTS | REASON FOR | RESULTS GIVEN |
|---|---|---|---|
| 1st | End Vertical Flues separately and more intensely heated. | Radiation losses at the oven ends compensated. | No black ends, carbonising time shortened, uniform heating of oven walls from end to end. |
| 2nd | Positive guiding of combustion gases in Regenerators. | Obtains full utilisation of Regenerators by avoiding dead ends. | Best effective heat, lowest consumption of heating gas for carbonisation. |
| 3rd | Oven Top Arches formed in Tamped Fireclay. | All unnecessary joints avoided, stronger construction. | No gas leakages, immunity from shaking of coal machine. |
| 4th | Improved brickwork bond in heating walls. | Less jointing with much stronger construction, | Increasing the tightness and stability of heating walls. |
| 5th | Special Shaped Headers in upper part of heating flues. | Increased heat radiation upon the stretchers for equalising the decreasing temperature of the flames | Uniform heat transmission in the whole heating wall even in high ovens. |
| 6th | Patent Tube Regenerators under separate damper control. | Greater heating surface in given area. | Stronger construction, regenerator evenly heated. |

FULLY PROTECTED BY BRITISH PATENTS. EXISTING PLANTS CAN BE RECONSTRUCTED TO INCLUDE "KOGAG" IMPROVEMENTS. A NUMBER OF "KOGAG" PLANTS ARE GIVING THE BEST RESULTS AND MAY BE INSPECTED.

*Estimates submitted for Complete Coke Oven Installations.*

**GIBBONS BROS. LTD., DIBDALE WORKS, DUDLEY, WORCS.**

LONDON :: MANCHESTER :: BRISTOL :: MELBOURNE

# GIBBONS

Engineers, who have appointed a Special Committee to investigate the question. A report was published in the "GAS JOURNAL," July, 1927. In the case of the coal experimented upon, the results in Table XI. indicate that at temperatures below 500° C. the liquid produced was acidic in character, and unless precautions are taken in the design of the plant, considerable wear and tear can be expected on certain parts of it. The undiluted aqueous distillate may contain up to 1 p.ct. of total phenolic substances, including phenol and its homologues, polyhydric phenols. Brittain, Rowe, and the author ("Fuel," 1925, 4, 263, *et seq.*) found 0·62 p.ct. in liquor obtained from a large-scale plant, of which the dilution was not known. The phenolic bodies consisted of phenols, cresols, xylenols, catechols, &c. These phenolic substances are valuable commercial products, and will no doubt be extracted and increase the total value of the products obtained from the process. The extracted liquor will then become a waste effluent, and where a plant is situated in an agricultural district it may be possible to apply some proportion to the land. In one case the use of the untreated liquor was successful, due no doubt to the presence of the phenols and ammonia.

The author wishes to express his thanks to the firms for their courtesy in supplying the information the paper contains. It was understood throughout that further details would be submitted by the firms' representatives at the meeting. The author is responsible for the opinions expressed.

## APPENDIX.

In order to obtain additional data relating to the various processes of low-temperature carbonization, the following questionnaire was sent to the leading firms; and the replies received are printed without alteration, and are arranged in alphabetical order.

**Copy of letter from Hon. Secretary, Joint Fuel Committee.**

Dear Sirs,—You may have noted from the Press that the Joint Committee is arranging a Carbonization Conference to be held in Birmingham from Feb. 21 to Feb. 24, and that on the Friday (Feb. 24) there will be a special discussion on the subject of low-temperature carbonization.

This discussion will be opened by Capt. F. S. Sinnatt, of the Fuel Research Board; and it has been thought that it would be of advantage to the general subject of low-temperature carbonization if opportunity were given to the exponents of different systems to take part in the discussion. The time will be limited, and consequently the contributions would have to be concise and short.

The Joint Committee would be glad if you could attend, or, alternatively, would send a short contribution to the subject, dealing more particularly with your own system. As a guide, and in order to ensure uniformity, we would suggest that you should in particular deal with the following questions:

(1) What is the main objective in your system?
(2) What class of coals, if any, are you confined to?
(3) Has the system been proved economic under large scale conditions?
(4) If so, give details.
(5) Does the system depend for its economic success on the value of the solid residue, or on the quantity and value of the oils?
(6) On what scale has the process been run continuously over lengthy periods?
(7) What is the nature of the solid fuel you would propose to make when using bituminous coals, and to what use would you propose to put it without further treatment?
(8) Do you propose to evaluate the liquid products net higher than the value of fuel oil?
(9) What is the nature of the tar produced? Are you troubled with emulsions, if not, what is the water content of the crude liquid products?
(10) Do you visualize your process working in the main with advantage in connection with
  (*a*) collieries;
  (*b*) gas undertakings; or
  (*c*) independently?
(11) What is the balance-sheet of products produced per ton of good-class caking bituminous coal, and what is the fuel consumption (if possible you should give results from a named coal)?

It is hoped that you will be able to provide a written contribution whether you are present or not, and if so, I should be glad if you would let me have it here by Feb. 1.

Yours faithfully,

---

## THE "FUSION" RETORT.

By F. G. DUNDAS, Chairman, Fusion Corporation, Ltd.

(1) The main object of the "Fusion" low-temperature retort is to provide a plant which will treat as large a variety of bituminous materials as possible in a standard design of plant—or with the least possible deviation from standard design—for the production of low-temperature crude oil and crude spirit.

(2) The "Fusion" retort is *not* confined to any particular bituminous material. It will treat practically any kind of coal, oil shale, torbanite, sawdust, &c., with only slight modifications in each case from standard design; but the throughput for any given size of retort will differ when treating different materials.

(3 and 4) It is difficult, at present, to give a definite answer to these questions. A plant consisting of four "Fusion" retorts each 50 ft. long by 4 ft. diameter has been at work in Nottinghamshire for some months, treating cannel coal. This coal was tested in the bulk testing retort at Middlewich. Two bulk tests were made, about twelve months intervening between the tests, and each test was made on about 10 tons of the material. These two bulk tests agreed fairly well, and on the results and data obtained the Nottinghamshire plant was designed and installed; but soon after it started to work it became apparent that some modification of details in the design would be required, which entailed shutting down the retorts, one by one, so as to enable the alterations to be made. Before the alterations were quite completed (and the plant was therefore only operating at about two-thirds of its capacity) it operated at a small profit. The coke residue contains about 24 p.ct. of ash and sells at 2s. per ton at works for use, after further pulverizing, as powdered fuel. Up to the present the gas has been burnt to waste.

(5) The economic success of any retorting process depends on the market for the products produced. If the material is high in ash, like oil shales, then the solid residue, or coke, would probably have no value, and the plant would depend on the crude oil and spirit produced for its revenue. If the material is low in ash, the solid residue will find a fairly ready market either in the form of briquettes or for powdered fuel purposes. Hitherto the large-scale installations of "Fusion" retorts have been, with one exception, for treating materials giving a high yield of oil and a low grade solid residue. The exception was a material giving a poor yield of oil, but in that case there existed a very good market for the solid residue for a special purpose.

(6) See answers to questions 3 and 4 in reference to one plant. "Fusion" retorts have also been run for weeks on end in Esthonia treating Esthonian oil shale, producing a large yield of crude oil and spirit; but in this case the solid residue was unsaleable. Another "Fusion" retort was run for months on another oil shale. In this case the "Fusion" retort was installed after many other types of retorts had been tried and failed. A "Fusion" retort has been operating for many months past treating sawdust and wood chippings, giving entire satisfaction; the products in this case being charcoal, wood tar, and ferrous acetate. It is proposed to extend this plant so that other products may be made. The same principle as is used in the "Fusion" retort has also been applied very successfully to low-temperature chemical process work, to the hydrating of lime, and to the drying of material which is difficult to dry in the ordinary types of dryer.

(7) The "Fusion" retort, as originally conceived, was not intended to produce a lumpy solid residue, or coke. The idea of the "Fusion" breakers or agitators was to provide a means for keeping the material, during carbonization, in a finely divided state, so that large surfaces could be subjected to heat, and in so doing obtain a rapid throughput of material at as low a temperature as possible, to enable true low temperature crude oil and crude spirit to be produced. Under these conditions the solid residue as discharged from the retort is about ⅜ in. cube and under in size. Experiments have been made with caking bituminous material on the larger experimental retort, resulting in a solid residue which contained a fair percentage of balls of about 1 in.

diameter. These balls formed a very good fuel for use on the office fires, &c.

(8) The evaluation of any low-temperature crude liquid product is, at present, a difficult matter; but under settled conditions and when good supplies of the liquids are available, it is thought that the products from the "Fusion" process will find a market at considerably above the price of fuel oil.

(9) The crude oil (or tar) produced in the "Fusion" process is, generally speaking, readily separated from water. There are some materials which produce an oil whose gravity is 1·0 or practically 1·0; and these in the presence of any dust in the oil produce an emulsion with water, making separation difficult and slow. This will happen irrespective of the type of retorting process used. Owing to the thorough agitation of the material during heat treatment, and the action of the "Fusion" breakers in keeping the wall of the retort tube free from scale, local overheating of the material does not occur, and the oil is produced at as low a temperature as possible and has as low a specific gravity as can be expected from any particular material treated. On the Nottinghamshire plant there is no trouble with emulsions. The water produced readily separates from the oil. Hundreds of thousands of gallons of this oil have been sold; and over long periods the water content has been under 1·0 p.ct.

(10) The "Fusion" retort will find its first field of usefulness in conjunction with collieries and similar undertakings (such as oil shale workings), and secondly with independent users, particularly firms who have adopted, or who may adopt, powdered fuel firing on a reasonably large scale, because the "Fusion" retort will form an ideal "link in the chain" in the production of powdered fuel. This retort—or modifications of it—will continue to find other uses, as mentioned at the end of No. 6 above.

(11) The fact that a *caking* coal is referred to, presupposes that the object of retorting is to produce a lump semi-coke. The "Fusion" retort does not, as mentioned in No. 7 above, usually produce a lumpy semi-coke. The following are weight balances from tests made—products per ton of material treated.

*a.—A Poor-Class Cannel Coal.*

| | | | | |
|---|---|---|---|---|
| Crude oil | 34·04 galls. | 325 lbs. | 14·5 | p.ct. |
| Water | 14·80 ,, | 148 ,, | 7·0 | ,, |
| Crude spirit | 3·00 ,, | 21 ,, | 0·9 | ,, |
| Gas | 2020 c.ft. | 161 ,, | 7·2 | ,, |
| Solid residue | 68·30 p.ct. | 1530 ,, | 68·3 | ,, |
| | | | 97 9 | p.ct. |

*b.—A Good-Class Cannel Coal.*

| | | | | |
|---|---|---|---|---|
| Crude oil | 53·95 galls. | 523 lbs. | 22·34 | p.ct. |
| Water | 15·20 ,, | 152 ,, | 6·78 | ,, |
| Crude spirit | 6·70 ,, | 52 ,, | 2·33 | ,, |
| Gas | 2240 c.ft. | 170 ,, | 7·58 | ,, |
| Solid residue | 58·50 p.ct. | 1310 ,, | 58·50 | ,, |
| | | | 98·53 | p.ct. |

*c.—A Medium Class Bituminous Coal.*

| | | | | |
|---|---|---|---|---|
| Crude oil | 21·30 galls. | 215 lbs. | 9·70 | p.ct. |
| Water | 16·80 ,, | 168 ,, | 7·50 | ,, |
| Crude spirit | 1·90 ,, | 14·5 ,, | 0·65 | ,, |
| Gas | 2390 c.ft. | 170 ,, | 7·58 | ,, |
| Solid residue | 73·0 p.ct. | 1635 ,, | 73·00 | ,, |
| | | | 98·43 | p.ct. |

*d.—A Good-Class Bituminous Coal.*

| | | | | |
|---|---|---|---|---|
| Crude oil | 30·61 galls. | 310 lbs. | 13·84 | p.ct. |
| Water | 31·08 ,, | 311 ,, | 13·88 | ,, |
| Crude spirit | 2·00 ,, | 15 ,, | 0·67 | ,, |
| Gas | 1865 c.ft. | 149 ,, | 6·65 | ,, |
| Solid residue | 63·0 p.ct. | 1411 ,, | 63·00 | ,, |
| | | | 98·04 | p.ct. |

The amount of fuel for heating the retort varies slightly according to the material being treated, and is usually between 9 and 12 p.ct., by weight, of the amount of material treated in the retort.

## "HIRD" PROCESS.

By H. P. HIRD, of British Carbonised Fuels, Ltd.

(1) The basic idea of the Hird process has been to provide a passage-way through the centre of the coal charge under carbonization for the easy and quick exit of the products of carbonization. This has been accomplished by having a rotating blade of a suitable cross section, which maintains a hole in the centre of the coal charge. The retort itself is built of a special make of cast iron, and is similar in shape to the ordinary coke oven, except that it has a bottom discharge, and the retort is discharged by the weight of the coke. The blades are inserted at approximately 1 ft. centres; and the number used depends on the length of the retort. The flue temperature is maintained at 600°-650° C.; and a special heating arrangement is adopted so that the cast-iron retort is not affected by impinging flame. Cast iron is used instead of fireclay, as it is necessary at this low temperature to get a quick transference of heat through the walls of the retort; and this cannot be accomplished with fireclay at these temperatures. When the retort is charged, a softening of the coal charge nearest to the side of the retort wall takes place; and this prevents any gases passing up the side between the coal charge and the retort, as in the case of the coke oven. Thus the gases are forced inwards, and find their to the centre passage and away. At the same time they give up any sensible heat which they contain, and heat-up the coal in the centre of the charge. In this way the gases are always being forced inwards to the coolest part of the retort, thus preventing cracking and decomposition of the primary oil. The Hird process has proved that a quicker rate of carbonization can be obtained when working under low temperatures than can be obtained under high-temperature conditions, owing to the gases passing inwards through the coal charge and giving up their heat to the colder coals they encounter. Also they are never heated to a temperature higher than that at which they are formed, neither is any heat lost in cracking the products. If a higher temperature is used in the Hird process for carbonization, it is found that the same effect takes place as in an ordinary coke oven; and a longer time is necessary for carbonization than with the lower temperature, which is opposed to the theory behind the modern tendency for higher and higher temperatures.

(2) The process will treat any class of coal. It will also carbonize successfully bituminous coal containing high percentages of volatiles.

(3) The process has been developed to the point of handling 10 cwt. charges successfully. The method has also been tried on a continuous vertical retort, but working under high temperatures.

(4) After operating several experimental retorts, a retort was built on the information obtained and operated for six months, carbonizing 10 cwt. charges intermittently, with the following results:

Dense hard coke containing as required 5-10 p.ct. volatile; high yield of oil containing over 30 p.ct. tar acids.

Easy discharge of coke.

Tests were carried out at varying flue temperatures —*i.e.*, 600°, 700°, 800°, 900° C.; and it was found that quicker carbonization took place at 600° than at the higher temperature of 900° C.

Trouble was experienced with the metal of the retort at the end of the period, due to flame contact with the retort and using ordinary cast iron. This appeared to be the only defect with the process. This trouble is being avoided in the commercial size plant under construction.

When working on a continuous vertical retort, it was found that during the ten weeks' run the following advantages were obtained:

No poking of the retort necessary during the whole time.

No pressure on the retort at any time.

Ascension pipe kept clean, and did not make-up as was the case under ordinary conditions.

No hanging of the coal charge.

The tests on the vertical retort were done under high-temperature conditions. It would be most interesting to see the effect under low-temperature conditions, as it would appear to be an advantage in assisting the passage of the coal through the retort, at the same time giving quick exit for the gases, either under high or low temperature conditions.

(5) Both the solid residue and the oils obtained are of good quality, with high yields of both per ton of coal as follows:

(*a*) Slack coal by carbonization under the process gives hard dense coke, highly combustible, and yields 14-15 cwts.

(*b*) The oil is of good colour, with a tar acid content above 30 p.ct.; the yield per ton of coal being at least twice the tar yield from a given coal under high-temperature carbonization. It is free from free carbon; and when distilled down to cracking-point, yields 12 p.ct. pitch.

Both products will sell at the highest market price for their class, and will contribute together to the economic success of the process.

(6) 10 cwt. charges per 12 hours for six months.

(7) Hard dense coke free from bubble structure,

which can be lighted with chips in the ordinary way. Suitable for domestic or industrial use.

(8) Yes, chiefly owing to the high tar acid content.

(9) The oil as produced can be washed direct with caustic soda, it not being necessary to distil the oil previously. Oil produced from Durham slack gives:

2 p.ct. water.
38 p.ct. tar acids.
60 p.ct. neutral oil.

The oil was first washed with caustic soda to separate the tar acids from the neutral oil, which are then distilled separately with the following results:

*Neutral Oil (Gallons per Ton).*

25 gallons spirit up to 200° C.
32 ,, light creosote oil to 270° C.
32 ,, heavy oil to 320° C.
25 ,, high boiling oil to 370° C.
12 ,, oil, vaseline nature above 370° C.

The pitch remaining is very small indeed; and it can be taken that the fraction of neutral oil is free from pitch. This oil does not crack at the highest temperature.

*Tar Acid.*

43 gallons high boiling acids to 300° C.
17 ,, viscous acids to 360° C.
At 360° C. vigorous cracking takes place, leaving 1 cwt. 2 qrs. pitch.

It is of interest to note that the pitch content is in the tar acid fraction only. This cannot be pitch in the ordinary sense, as it was in the first place soluble in caustic soda. It would appear to be of a resinous nature. On no occasion have emulsions been obtained. The maximum water content is 2 p.ct.

(10) All.

(11) Coal used (mixture of Beeston and Silkstone).

*Analysis:*

| | | |
|---|---|---|
| Moisture | 9·13 p.ct. | |
| Ash | 6·80 p.ct. | on dry basis. |
| Volatile | 34·35 p.ct. | |

*Calorific Value.*

13,500 B.Th.U. average.

*Balance.*

| | | | | |
|---|---|---|---|---|
| Coke, average | 13,250 B.Th.U., | 14·5 cwt. per ton, | | 22,260,000 |
| Crude oil, average | 16,000 ,, | 22 gallons ,, | | 3,625,000 |
| Crude spirit, average | 18,000 ,, | 4 ,, ,, | | 720,000 |
| Gas, average | 700 ,, | 5000 c.ft. ,, | | 3,500,000 |

*Fuel required for Carbonization.*—On the plant on which these figures were obtained, the amount of fuel required for carbonization could never definitely be ascertained, owing to radiation loss; but it is expected to be lower than that required for higher-temperature carbonization, owing to the quicker rate of carbonization by the Hird process and also to the lower temperature required for carbonization.

## "ILLINGWORTH" PROCESS.

By Dr. S. R. ILLINGWORTH, of the Illingworth Carbonization Co., Ltd.

The main object of the Illingworth system of carbonization is the enhancement of low-grade coal, and in suitable localities its main aim is the production of a solid fuel, concurrent with liquid and gaseous products.

The system is applicable to any class of coal provided there be present, when fines are used, a minimum quantity of bituminous coal, such that the coal charged has a caking index (Campredon) not less than 9.

It is, of course, essential that the coal used be clean or cleaned, inasmuch as the value of the residual fuel for domestic purposes is dependent on the ash content.

This system is not confined to any particular size of coal, and has successfully dealt with sizes from nut coal down to colliery dust (air borne) which passed 90 mesh.

The system can utilize wet or dry coal, inasmuch as there is incorporated in it an efficient and economical feature for drying. The system has been developed up to a throughput of 42 tons of coal per day. On this basis the economic side has been proved.

The plant is situated at the gas-works, Pontypridd, wherein an existing setting of high-temperature intermittent verticals has been converted to chamber ovens for low-temperature working. Here the initial three ovens of 30 cwt. capacity have been at work for three years (apart from the coal strike). A further four ovens were put to work 2½ years ago.

These ovens are 12 ft. high, 9 ft. 6 in. long, and 14 in. wide. They are constructed of fireclay refractory flue tubes, between which are disposed H-section cast-iron conductors, the function of which is to conduct the heat into the charge, thus shortening the time of carbonization, and to produce a semi-sized fuel. The effectiveness of this is apparent from results with and without the conductors. Without the conductors 28 hours was insufficient to carbonize, whereas with the conductors in operation carbonization is complete to a homogeneous product in 6 hours. This system of construction allows the metal to be under no stress or strain, it permits of easy renewal if such is required, and it reduces capital and maintenance costs to a minimum.

A retort of 3 tons capacity has recently been brought into satisfactory commission, thus halving previous labour charges. These retorts can be fired by producer gas generated from the fuel, or by direct use of the gas generated in the process. The consumption of fuel per ton of coal carbonized is 6 p.ct. thereof (equivalent to 18 therms). This figure applies to wet or dry coals, inasmuch as wet coals are dried by the sensible heat of the discharged fuel in a specially designed car, which carries out the five-fold purpose of drying the coal, cooling the fuel, performing any mixing of coals desired, incorporating the breeze in the next charge, and finally acting as a transporter of the fuel from the retort to fuel bunker.

The solid product (8 p.ct. volatile) is of dense hard nature which produces less than 3 p.ct. of breeze on 200 miles transport. It is in use for the following purposes: Domestic, central heating, bakeries, tanneries, anthracite stoves, cupola work.

The oils are evaluated at fuel oil prices. The tar produced is a brown tar of sp.gr. 1·04 to 1·08, according to the coal. It yields the following fractions:

| | |
|---|---|
| 170° C. | 8·5 p.ct. |
| 170° to 230° | 12·0 ,, |
| 230° to 270° | 18·0 ,, |
| 270° to 340° | 23·5 ,, |
| 340° upwards | 38·0 ,, |

The water content of the settled tar is 5·8 p.ct., according to atmospheric temperature.

The process is applicable to colliery undertakings or gas-works.

## "L & N" PROCESS.

Copy of Letter from Mr. HARALD NIELSEN (Engineer and Technical Consultant, Sensible Heat Distillation, Ltd.).

After carefully considering the forthcoming Congress at Birmingham, I have come to the conclusion that from our side we have already offered certain criticisms on the work conducted by Mr. Sinnatt and his assistants of the Fuel Research Board, and have not yet received any satisfactory reply, so that any further remarks on our side would be a mere waste of time. We are not yet in operation with our big Leicestershire plant; but this will only be a matter of weeks now, so until then I really have nothing very much to say.

With reference to the work at our Barnsley plant, I have already, on behalf of my Company, published quite a lot.

## "COALITE" PROCESS.

By Col. W. A. BRISTOW, M.I.E.E., M.I.A.E., F.R.Ae.S., Consulting Engineer, and Managing Director of Low Temperature Carbonisation, Ltd.

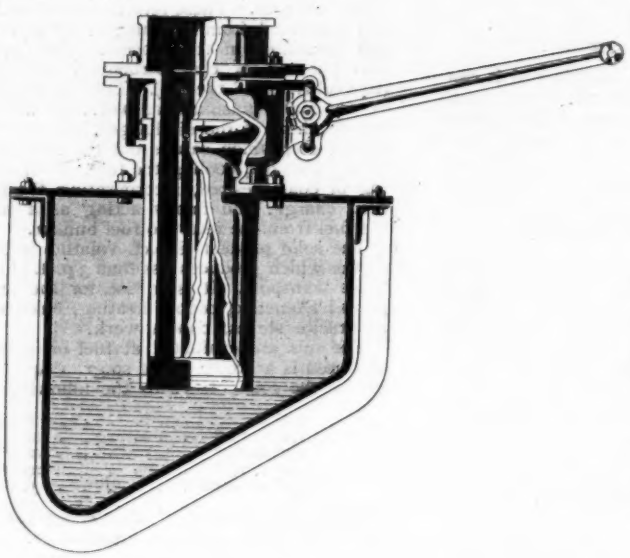
The main objective of low-temperature carbonization as practised by my Company is the manufacture of smokeless fuel. In the year 1906 Mr. Thomas Parker, of Wolverhampton, who made the first practical steps towards founding the process, filed a specification No. 14,365, of 1906, the preamble of which commences as follows:

> This invention relates to the production of fuel by the partial destructive distillation of coal at low temperature, whereby a fuel is produced of uniform composition and of high calorific value whose combustion in an open fire grate yields a high temperature and is practically smokeless, and whereby also in the process of its production gas, tar, and ammonia are yielded, so that thus the cost of production of the fuel is such as to allow of its ready sale on the market.

This sets out very clearly the fundamental objects in view; and in all the ups and downs during the last twenty years our predecessors who have grappled with this problem have never departed from this main idea, and it remains to-day the chief objective of the present Company.

Adherence to this idea dictates the design and operation of the plant in every respect, as in order to reduce

# An essential to modern Gas Works practice



## CORT'S PATENT ANTI-DIP VALVE

**Has proved itself after long and constant service to be of outstanding efficiency. To obtain the maximum results from your existing or proposed settings its installation is a recognised necessity—in fact, it is now considered an essential of modern practice.**

Definite advantages which should create your interest in this apparatus are:—

1. Substantial increase in therms and "make" per ton.
2. Simplicity in construction; non-contact of working parts with the foul gas assures certainty of action.
3. Each retort under independent control.
4. Permits working under level gauge conditions.
5. Ordinary Dip Pipes can be replaced without alteration to the hydraulic main.
6. Overcomes sealing difficulties where main is not level.
7. Elimination of stopped pipe troubles.
8. Low initial cost—quickly recovered by economy effected.

Consider the installing of Cort's Anti-Dip Valve when next you propose making extensions, alterations or repairs to your Retort Benches.

These Valves are now in use in approximately 200 Gas-works (a few of which are appended), and we continue to receive most satisfactory reports as to their working, fully confirming our claims for them.

| | | | | |
|---|---|---|---|---|
| Athlone. | Clevedon. | Hoddesdon. | Oxford. | Scarborough |
| Aldershot. | Colchester. | His Majesty's Fuel Research Station. | Peterborough. | St. Margarets |
| Bristol. | Colwyn Bay. | Haslemere. | Pembroke Dock. | Swaffham. |
| Bangor. | Dungannon. | King's Lynn. | Rochester. | Swindon. |
| Banbury. | Desborough. | Knowle. | Runcorn. | Wakefield. |
| Beckton. | Doncaster. | Leeds. | Romford. | Weston-super-Mare. |
| Blackpool. | Glastonbury. | Mablethorpe and Sutton. | Spenborough. | Willenhall. |
| Cambridge. | Gosport. | Newark. | Sleaford. | Woolton. |
| Cardigan. | Hertford. | | Snodland. | York, etc., etc. |
| Chelmsford. | | | | |

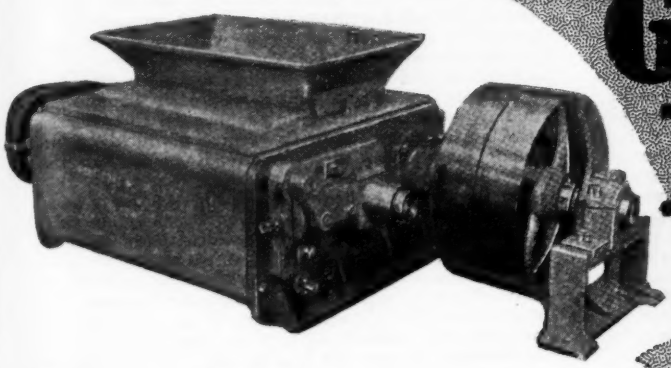
*Send us your enquiry direct or through your usual contractor.*

ROBERT CORT & SON LIMITED

Reading Bridge Ironworks~READING

# For Satisfaction in COKE GRADING PLANT Specify

Pat. No. 179090/21



# Cort's Coke Cutting Machines and Rotary Screens

The friable nature of Coke demands specially designed plant, and after many years' specialization in the production of machinery for handling this material, Cort's Coke Cutting Machines and Improved Rotary Type Screens have been introduced and have entirely fulfilled the requirements demanded by the most discriminating Engineers interested in the Grading of Coke.

Mr. Hardie, Chief Engineer of the Gas Light & Coke Company, in his Presidential Address to the Southern Association of Gas Engineers, and in reference to the subject of Coke, said:—

"I consider that the Gas Undertakings would be well advised to equip themselves immediately with the necessary plant to satisfy properly the inevitable demands of the future."

It is pleasing for us to state that several of our Machines have been ordered for the various stations of the Gas Light & Coke Company, whilst other Gas Companies and Collieries who have also recently placed orders for these machines are:—

GAS COMPANIES—Bath, Birmingham, Brighton, Budleigh Salterton, Burnley, Commercial, Doncaster, Eastbourne, Exmouth, Hampton Court, Harwich, Hastings, Herne Bay, Lea Bridge, Leatherhead, Newcastle, Sevenoaks, Slough, South Suburban, Walton-on-Thames, Wandsworth, Woking, &c., &c.

COLLIERIES—Dinnington Main, Grassmoor, Nunnery, Priestman, South Yorkshire, &c., &c.

ROBERT CORT & SON LIMITED

*Reading Bridge Iron Works,*

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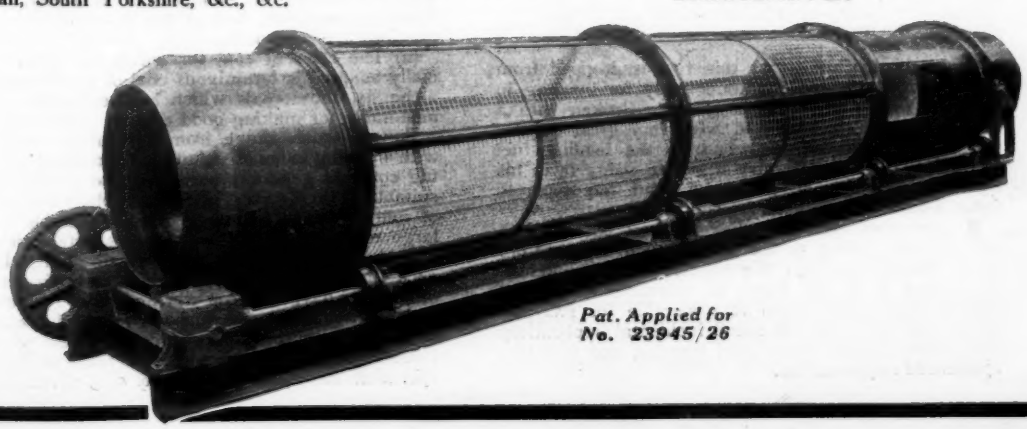


Pat. Applied for No. 23945/26

working costs it is essential that the smokeless fuel should be turned out of the retorts in a shape ready for the fire and capable of withstanding handling and transport without undue breakage.

It is important to differentiate between processes such as ours and those intended primarily for the conversion of coal into oil, or soft or non-coking coal into pulverized fuel, or any other similar purposes.

For the present we are confining our attention to the distillation of bituminous coals; and in this class we can deal with practically any coal, either straight or blended, as we can control the result to almost any extent desired by selection and treatment. The yields from different coals vary, but not to a very great extent; and up to the present no coal has been submitted to us for test that could not be profitably dealt with by our process.

The system has been proved economical under large-scale conditions. Our works at the present time are carbonizing about 1500 tons of coal per week, yielding over 1000 tons of "Coalite," 28,200 gallons of oil, 3750 gallons of benzole, and 7 million c.ft. of rich gas. All "Coalite" is delivered from the retorts direct into railway wagons for delivery all over the country, and the coal at the works from raw coal to finished product is never handled except by automatic conveying machinery.

The tar oils are sold for months ahead to refineries in this country, and buyers on the Continent have also made satisfactory offers for large quantities. The prices are higher than those obtained for gas-works tar oils, and the value of the oil obtained from one ton of coal is greater than the cost of the coal.

In addition, each ton of coal produces about 14 cwt. of smokeless fuel which sells readily at prices equal to that paid for best house coal.

There is also a profit to be made on the gas, for the rich gas made can be passed on to a gas undertaking at a reasonable price, and producer gas used in lieu thereof for heating the retorts and sundry services about the plant. The gas has a calorific value of about 700 B.Th.U. per c.ft., and in the opinion of the Fuel Research Board it ought to pay any gas company to take this gas at 2d. to 2½d. per therm.

It follows, therefore, that the economic success of the system depends equally on the value of the solid residue and on the oils, both of which command a ready market at satisfactory prices.

The process has now been running at the new works continuously since the beginning of July last, and the first batteries have been operating without a break since being started up. The No. 1 battery of 32 retorts has now been working night and day for seven months, and there is no sign of deterioration, or damage to any of the parts. There is no difficulty whatever in discharging the smokeless fuel from the retorts, and I have no hesitation in stating that the technical difficulties that have hitherto proved almost insurmountable have been overcome.

In distilling bituminous coals, we make only one class of smokeless fuel—that which is sold under the trade name of "Coalite." The approximate composition is as follows, but, of course, it varies slightly according to the coal used:

| Analysis. | As Sampled. | Dry State. |
|---|---|---|
| | P.Ct. | P.Ct. |
| Fixed carbon | 83·47 | 85·88 |
| Volatile matter | 7·20 | 7·42 |
| Ash | 5·63 | 5·80 |
| Total sulphur | 0·87 | 0·90 |
| Moisture | 2·83 | .. |

*Colour of ash.*—Light brown.
*Calorific value.*—Calculated from proximate analysis 14,492 B.Th.U. per lb.
*Evaporative power.*—14·98 lbs. of water per 1 lb. of fuel.
*Arsenic.*—No trace.

Without further treatment this fuel is dropped from the retort in size and condition ready for burning in any type of grate, open or closed. Broken into a suitable size, it is employed with very great success in anthracite stoves; and one of the leading fuel technologists in the country has been using it in his own stoves for some time past, and has reported upon it in very satisfactory terms.

In powdered form it makes the best possible pulverized fuel, owing to the high carbon content, dry state, fluidity through the burners, and smokelessness; and it is not liable to spontaneous ignition when stored. It is also very suitable for gas producers and a number of small incidental applications like smithy work, steam road wagons, and for other specialized requirements.

In the questionnaire submitted by the Joint Fuel Committee to the contributors to this discussion, in section 8 I am asked as to how I propose to evaluate the liquid products and whether I consider them of higher value than the fuel oil. To this I am in the position to reply that it is not necessary for me to hazard any estimates, as the whole of the liquid products have been sold regularly for months past, are sold for months ahead, and at prices which are higher than the value of the fuel oil constituent.

The tar oils contain: Crude naphtha, carbolic oils, creosote oils, anthracene oils, and soft pitch. The finished products comprise: Refined motor spirit, rubber solvent, cresylic acid, gas wash-oil, fuel oil, and lubricants and other subsidiary products. We are not troubled with emulsions, and we are under contract to supply all our tar oils with a water content of not more than 3 p.ct.

With regard to the best directions in which our process can be advantageously worked, I would state that it is equally suitable for application to collieries, gas undertakings, or in the centre of thickly populated towns where there is a ready market for the gas and the smokeless fuel.

In the case of collieries, nearly all varieties of good bituminous small coal, when well washed, are suitable for making "Coalite," which with its bye-products would vary little, if at all, from the standard figures mentioned above; and after paying for the cost of the process and allowing for interest and depreciation on the plant, there would be a margin of profit impossible to obtain by any other method of dealing with the coal.

Large gas undertakings could employ the process to advantage, as in most cases they have already a market for the fuel which could be considerably improved upon when "Coalite" is subsituted for coke, and they would provide for themselves at the same time large quantities of gas of calorific value of 700 B.Th.U. which could be advantageously used for enrichment.

There is also considerable scope for the establishment of independent plants in selected areas—for example, Newcastle. Here it is proposed to establish a plant practically in the city, on the water's edge, and where there is a large surrounding demand for smokeless fuel and a ring of pits which can be relied upon for continuous supplies of suitable coal at a reasonable price.

A representative balance-sheet of products yielded per ton of good-class caking bituminous coal is as follows, the coal being a mixture of Dalton Main singles and Dalton Main washed slack.

From July 1 to Nov. 17 last, 11,718 tons of this coal were carbonized, yielding:

| | | |
|---|---|---|
| "Coalite" | 8,091 tons | = 13·8 cwt. per ton |
| Tar oil | 220,000 galls. | = 18·8 galls. ,, |
| Spirit | 29,295 ,, | = 2·5 ,, ,, |
| Gas (700 B.Th.U.) | 53,551,260 c.ft. | = 4570 c.ft. ,, |

The heat consumed was 25 therms per ton of coal carbonized.

In conclusion, I claim that there is no longer any need for the Government and local authorities to speculate as to when, if ever, a smokeless fuel is going to be produced, as I submit it is being produced now on a commercial scale and at a most satisfactory profit. Further, that trials of the fuel all over the country to the extent of many thousands of tons burnt in all classes of grates and stoves show that it is more than acceptable to the consumer.

## "MACLAURIN" PROCESS.

By R. MACLAURIN, of Maclaurin Carbonisation, Ltd.

(1) The Maclaurin process was evolved with the object primarily of supplying a smokeless fuel for domestic purposes, and at the same time producing gas, oil, and ammonia.

(2) The class of coal for which the plant is especially adapted is bituminous coal of low coking index—that is, those coals which by themselves would be unsuitable for making good coke in coke ovens.

Suitable coals range from non-coking up to those with a coking index of 16. High coking and intumescing coals as generally used for coke making are unsuitable. Small coals are unsuitable. The best size of coal to use is "Jumbo" nuts, but treble nuts and large coal can also be dealt with satisfactorily.

(3, 4, and 6) The Maclaurin plant at the Dalmarnock Gas-Works, Glasgow, which carbonizes 100 tons of coal per day, has been working since August, 1925, and has not had to be shut-down since for any faults or difficulties within the producers. A few mechanical troubles common to machinery or plant in continuous operation for 24 hours per day and seven days per

week have arisen; but these have been only of minor importance.

The plant was shut-down during the coal stoppage, owing to lack of fuel. Since the coal stoppage the plant has been carbonizing from 50 to 70 tons of coal per day; the amount depending upon the quantity of gas required by the Gas Department, who are using the gas for heating settings of vertical retorts.

Only four out of five of the producers of the installation have been working, owing to no outlets being available for the surplus gas over that required for the vertical retorts.

(5) The economical success of the Maclaurin process depends upon the values received for all the products. Of the three principal products—viz., smokeless fuel, gas, and oil—each contributes a large quota of the total revenue.

(7) The solid fuel made is graded into three sizes. The large size, over a ¾-in. screen, is sold particularly for domestic purposes—namely, room fires and kitchen ranges.

The large fuel has from 7 to 8 p.ct. of ash, and burns freely in domestic fires. The volatile matter varies from 4 to 6 p.ct., but the reactivity of the fuel is very high.

In tests reported by Edgar C. Evans to a former conference, the Maclaurin smokeless fuel was at the head of the list, in respect of reactivity.

The sulphur content is fairly low.

The medium-sized smokeless fuel is suitable for anthracite stoves or hot water apparatus. The fines are used for boiler firing, and could also be used for pulverized fuel. The ash of the coal is largely concentrated in the fines.

The large fuel is hard enough for use in Scotch blast furnaces; the average of 34 tests for crushing strength giving over 800 lbs. per sq. in,

(8) The crude oil is valued at the price received for it from the Chemical Works Department of the Glasgow Corporation—viz., 6d. per gallon. The oil is not likely to be used for fuel purposes so long as creosote oils are at higher prices than fuel oil, as this oil is particularly rich in phenolic compounds.

(9) The crude oil (it is called oil to distinguish it from tar) is a thick brownish oil with a specific gravity about 1·04, and contains very little free carbon.

The oil and water separate readily in collecting tanks; and after settling, the oil contains about 3 to 6 p.ct. of water, which is taken out in a centrifuge, after which the oil is ready for distillation or for direct use.

(10) I visualize the Maclaurin process as being worked most economically at the pithead, in colliery areas, supplying cheap gas over a wide area to a number of gas-works, all interlinked and worked under one authority like the Electricity Board. The collieries would then become manufacturers of smokeless fuel and oil, and suppliers of gas in bulk. Gas undertakings would distribute the gas.

In areas outside colliery districts, the gas undertakings would possibly be the principal users; but they would then cultivate the industrial load more successfully than at present.

The reason for this belief is because a 240 B.Th.U. gas can be manufactured in large volumes so cheaply by the Maclaurin process that it can be sold to industries in the neighbourhood at a price which would induce them to turn from the use of raw coal and oil as sources of heat and power. Also, by manufacturing this gas on a scale to meet the demands of industry, its cost would be so low that it could be distributed to domestic consumers at prices which would induce them also to give up the use of raw coal.

The gas presently in use in Nuneaton is under 240 B.Th.U. per c.ft., and this gas is used satisfactorily for heating, lighting, and cooking.

In certain industries such as the iron and steel and ceramic industries, where gas is used in very large volumes for heating purposes, the plant would be erected at the site to save cost of mains. Relatively small quantities of gas could be supplied from the works to meet the domestic needs of such a district.

(11) The balance-sheet of the products yielded per ton of low-coking bituminous coal is given below. The figures are the average results obtained during the three months ended February, 1927, and were obtained under every-day working conditions.

*Yields per Ton of Coal.*

| | | |
|---|---|---|
| Oil in gallons | 20·38. | Water content about 4 p.ct. |
| Sulphate of ammonia in lbs. | 31·94 | |
| Gas, c.ft. | 33849·0 | |
| Calorific value | 239·5 | |
| Therms | 81 | |
| Solid fuel | 9·9 cwts. | |

There is no fuel used for carbonizing the coal except that which is burned inside the plant and which appears again in the gas.

The total products given are therefore available for sale, except any fuel or gas required for steam raising.

The amount of steam used for power and for the producers is approximately 500 lbs. per ton of coal carbonized.

During the period for which the above results are given, about twenty different coals, mostly Lanarkshire, were passed through the plant. The analysis of these coals would be very similar to the following:

| | |
|---|---|
| Moisture | 9·80 p.ct. |
| Volatile matter | 33·75 ,, |
| Fixed carbon | 50·87 ,, |
| Ash | 5·58 ,, |
| | 100·00 |

To indicate the economical advantages of the Maclaurin process, a comparison of the cost of obtaining the same number of therms in non-recovery producers and in Maclaurin producers working under similar conditions is given below. From this it will be seen that if only 12s. is obtained for the solid fuel from one ton of coal, 8s. for the oil, and 1s. for the ammonia, Maclaurin gas of 240 B.Th.U. will be obtained at 0·62d. per therm less than 140 B.Th.U. non-recovery producer gas. Some advantages of the 240 B.Th.U. gas are also given.

*Comparison of the Cost of Obtaining the Same Number of Therms in Non-Recovery Producers and Maclaurin Producers.*

**Basis used, 1,820,000 therms—*i.e.*, the normal number of therms obtainable from 10,000 tons of double nuts coal in non-recovery producers.**

| — | Non-Recovery Producers. | | Maclaurin Producers. |
|---|---|---|---|
| | £ | | £ |
| Coal, 10,000 tons of double nuts at 18s. | 9,000 | | .. |
| Coal, 24,000 tons of treble nuts at 20s. | .. | | 24,000 |
| Labour at 2s. per ton of coal. | 1,000 | | 2,400 |
| Supervision, &c. | 500 | | 600 |
| Repairs and maintenance | 1,000 | | 1,200 |
| Rent, taxes, and insurance | 1,000 | | 1,200 |
| Steam, power, and lighting | 1,000 | | 1,000 |
| General charges. | 500 | | 600 |
| | £14,000 | | £31,000 |
| Allow for depreciation, 10 p.ct. on £15,000. | 1,500 | on £30,000 | 3,000 |
| Allow for interest, 10 p.ct. on £15,000 | 1,500 | 35,000 | 3,500 |
| Cost of 1,820,000 therms = | £17,000 | | £37,500 |

= 2·24d. per therm.

*Deduct Bye-Products.*

| | s. | d. | |
|---|---|---|---|
| Solid fuel, 10 cwt., valued at | 12 | 0 | |
| Oil, 16 to 20 gallons ,, | 8 | 0 | |
| Ammonia and phenols ,, | 1 | 0 | |
| | 21 | 0 | |
| 24,000 tons at 21s. | | | 25,200 |
| Cost of 1,820,000 therms = 1·62d. per therm. | | | £12,300 |
| Annual cost in non-recovery plant | | | £17,000 |
| ,, ,, ,, Maclaurin plant | | | 12,300 |
| Saving per annum | | | £4,700 |

Maclaurin gas has the following advantages over non-recovery producer gas, in addition to its lower costs:

(*a*) Its flame temperature is from 200° to 300° C. higher.
(*b*) It radiates its heat more freely.
(*c*) It gives a longer flame, and therefore less local heating.
(*d*) Being cool and clean, it is more easily distributed throughout a works.
(*e*) The calorific value varies very little from 240 B.Th.U.
(*f*) Because of (*d*) and (*e*), the temperature in furnaces can be very readily controlled.

## "PLASSMANN" PROCESS.

The Plassmann process of low-temperature carbonization has been essentially designed with a view to the production of smokeless fuel of a suitable quality for domestic purposes, using as a starting material

fine coal and slack, for which at the present time there is comparatively little demand. The Plassmann retort is essentially a retort in which the fuel lies at rest in thin layers during the process of carbonization, and is externally heated. Owing to the fact that the coal lies at rest and is under a certain degree of compression, depending upon the extent to which it is packed by the feeding apparatus, it has been found possible to deal in this retort not only with coal of the usual coking characteristics, but also with coal which in ordinary circumstances will not yield a coherent coke.

A plant which is to consist of eight units, each to deal with a daily throughput of 50 tons of coal, is now in process of erection at the Prosper Mines, near Essen. The first unit of this plant has now been in operation for a period of five months, and the outcome of this working has been entirely satisfactory and has proved that the results obtained during the two years' operation of a small experimental plant dealing with approximately 1½ tons per day can be repeated and, indeed, improved upon, on a large scale. This small plant has run for periods up to twelve months without any stoppage, so that the problem of the mechanical design can be considered as satisfactorily solved.

The bulk of the product of any process of low-temperature carbonization is, of course, the smokeless fuel, and the economic success of any process of low-temperature carbonization must, to a large extent, depend on the value of the solid residue. Again, the crude oils and gas are naturally of great importance in determining the profits which can be expected from any process of low-temperature carbonization. With a yield of approximately 18 to 20 gallons of tar or crude oil per ton, it is clear that a difference in value of even 1d. per gallon is of considerable importance. The tar produced in the Plassmann process can, we think, be fairly stated to be of exceptional quality, and from inspection and analysis it will be seen that it has been subjected to practically no "cracking" whatever. The dust content is negligible (about 0·2 p.ct.) and the pitch content of 27·1 p.ct. is also very low. We prefer for the present in our calculations to value the oil as a fuel oil; but it is already demonstrated, as a result of experiments, that it can be used as an impregnating oil for timber, after a very simple process of distillation, and it is therefore reasonable to anticipate that the value of the crude oil will be very much higher than its value merely as fuel. The water content of the crude products is under 1 p.ct., so that no trouble whatever has been experienced with emulsions.

To answer the question as to whether a process of low-temperature carbonization is better worked in connection with collieries, gas undertakings, or independently, involves the consideration of a very large number of different factors. With a gas production of 20 or more therms of rich gas per ton of coal treated, it is naturally of very great importance to the economic results of a process whether this gas has to be sold on its calorific value only for heating purposes, or whether it can be disposed of for enriching purposes, and thus valued at a much larger figure per therm. Installation at or close to a colliery has advantages in that the cost of handling the coal is reduced to a minimum, as the fines can be taken direct from the dry separation plant to the carbonizing plant with a minimum loss of caking properties as the result of oxidization or storage. It will thus be seen that the answer to the question put regarding the most suitable location for the plant involves consideration of a large number of factors which may vary from time to time, and it is impossible to give a general answer which would apply in all cases.

As regards the balance-sheet of products per ton of coal, the following figures showing the results with a fine dust coal from the Prosper Mines will give an indication of the yield which can be expected from ordinary bituminous coals with approximately 25 p.ct. of volatile contents.

| | | |
|---|---|---|
| Smokeless fuel | 80 | p.ct. |
| Tar | 6 | ,, |
| Crude petrol | 0·3 | ,, |
| Gas | 23 | therms |

Owing to the design of the oven and to the method of heating adopted, whereby the flue gases are continually re-circulated through the heating chambers, the heat required for maintaining the temperature of the oven is extremely low, and at the plant at the Prosper Mines has been approximately 15 therms per ton of coal carbonized. The process of carbonization itself appears practically to absorb no heat, and the entire consumption is required to make up for losses through radiation and convection, and the small loss in quenching the coke.

## "SALERMO" PROCESS.

By A. T. DE MOUILPIED, Director, Salermo, Ltd.

The "Salermo" retort belongs to the class of externally-heated retorts with continuous feed, the material heated undergoing continuous regular stirring. An integral part of the process is the pre-drying and preheating by means of waste heat of the material to be carbonized.

The retort consists of a series of troughs under a common roof, forming a single carbonizing chamber. Along and above each trough is a shaft provided with closely-set paddles. The paddles can be made to revolve at any desired rate, and in either direction. The function of the paddles is to keep the material in constant motion, so that heat exchange between the material and the heated trough is facilitated, as also between particle and particle. The inside metallic surfaces are also kept clean and free from deposit.

The material itself is fed in automatically and continuously from the pre-drier; and because of the stirring to which it is subjected, it tends to behave like a fluid, and passes very easily through the retort. To secure an even flow, the best size for the material as fed in is ⅜ in. downwards.

The distillation products are filtered hot in the carbonizing chamber, before any condensation takes place, through dust extractors of a new type. The gases and vapours then pass through air and water-cooled condensers of special design, leading to a separation of the products of condensation into two fractions. The coal itself is raised to a temperature not exceeding 500°-550° C.; and the highest temperature in the gases is 450°-460° C.

The throughput of the plant is high for its size; and the construction allows of considerable flexibility in operation, as it is possible to vary the rate of charging, of drying, of heating, and of carbonizing.

The main objective of the system lies in the industrial applications of its products, solid, liquid, and gaseous, rather than in the direct production of domestic smokeless fuel.

The system is not confined to any particular class of carbonaceous material, and has dealt successfully with lignites, cannel coals, non-caking, and highly caking coals.

The system is working abroad successfully on the scale of over 450 tons daily. It depends for its economic success on the particular uses made of the solid and liquid products. Units of 25 tons a day have been working continuously over long periods; and 50 ton units are now working.

The fuel produced is small, containing some 8 to 15 p.ct. of volatile matter, according to requirements; and one of its applications is for direct feeding, while hot, on to the chain grates of tube boilers. It can also be used in a pulverized form. If the original material is of a caking nature, from 30 to 45 p.ct. of the semi-coke is obtained in an agglomerated form suitable for use as domestic fuel.

It is certain that the value of the liquid products will be higher than that of the tar as fuel oil.

The tar produced is a true primary tar; and owing to the system of dust extraction, there is but little trouble with emulsions.

The system is in operation in connection with the heating of industrial boilers and the manufacture of metallurgical coke. It offers great advantages in connection with gas-works and collieries, particularly as regards the latter, on coals of low grade.

Typical results on Durham coal are as follows:

| | Per Ton. | P.Ct. by Wt. |
|---|---|---|
| Semi-coke | 14·5 cwts. | 72·50 |
| Dry tar | 20·9 galls. | 9·95 |
| Gas | 3710 c.ft. | 8·85 |
| Liquor | 18·2 galls. | 8·12 |
| Loss | | 0·58 |
| | | 100·00 |

The calorific value of the gas varies from 700 to 870 B.Th.U. per c.ft., according to the coal used.

The fuel consumption is on the average equal to 12 therms per ton of coal carbonized, when the original material does not contain more than 12 p.ct. of moisture.

## "SUTCLIFFE" PROCESS.

By E. R. SUTCLIFFE, of Sutcliffe, Speakman, & Co., Leigh, Lancs.

Our process—which is variously referred to as the "Pure Coal Briquette" process, the "Sutcliffe-Evans" process, and the "Sutcliffe" process—may be divided into two sections, one of which is carbonization pure and simple, and the other, in which the

coal or fuel is first briquetted without a binder prior to carbonization.

Our main objective in these systems is to procure a smokeless fuel for domestic purposes, and particularly one to take the place of anthracite, at the same time to recover the oils and tars given off during carbonization.

In our process of carbonization, the fuel—which must be in a lump state, either in the form of lump coal or of briquettes—passes in at the top of our retort, which is constructed on lines almost identical to a blast furnace. During its passage down the retort it is subjected to gradually increasing temperature until it reaches the hottest zone, which is at a temperature of round about 800° C. As it passes farther down the retort, the charge is gradually cooled down, and passes out through the discharge mechanism in a carbonized and cooled state.

The heating is effected by the sensible heat of circulating gases, and consequently the system comes under that heading of processes designated as internal heating. The effect is to give a progressive distillation of the material as it passes down the retort, with the result that the characteristic tars of low-temperature carbonization are secured, with high yields of sulphate of ammonia, due to the higher final temperature.

In regard to the classes of coals that may be treated, any lump coal may be carbonized, provided it does not run together and choke-up the passage of the circulating gases. For instance, dealing with Lancashire coals, 7 ft. coal, Crombouke coal, and 6 ft. coal can all be passed through the retort without difficulty, while there are many similar classes of coal in the country which would not stick or weld together to too great an extent and which could therefore be used in retorts of this character.

In the case of small coals, it is necessary that such should be briquetted, and in that case the coal is first ground to a fineness such that all passes 100 mesh—in short, to a similar degree of fineness to pulverized coal firing. This finely-ground coal is then made into briquettes under heavy pressure without binder; such briquettes then taking the place of lump coal in the retort.

In the case of strongly swelling coals, the swelling is adjusted by blending with previously carbonized fines or other types of coal in such a proportion as to prevent undue swelling.

Tests have shown that most coals possess a critical temperature at which swelling will take place if the carbonization is conducted too rapidly through a certain temperature range. In general, we have found that such a range is limited to some 30° to 80°. As an instance, Lancashire 4-ft. coal commences to swell when a temperature of 438° C. is reached, and stiffens up again after passing 473° C., a difference of 35°. If the increment of temperature is sufficiently slow between 438° C. and 473° C., swelling does not take place.

In the case of 7-ft. coal, the softening-point is 423° C. and stiffening-point 462° C.—a difference of 29°.

In the case of Trencherbone, the softening-point is 437° C. and stiffening-point 467° C.—a difference of 30°.

In the case of Arley, the softening-point is 432° C. and the stiffening-point 509° C.—a difference of 77°.

The above figures are taken on briquetted material.

All may be passed through the retort without fear of sticking, except Arley; and provided the rate of increase of temperature through the critical range is not too high—viz., does not exceed one degree in three minutes—swelling is avoided.

By blending and admixture of fines, the above rate of carbonization through the critical range can be varied.

By studying coals and determining these critical temperatures and adopting the blending or adding back of previously carbonized fines, swelling and sticking-up in the retort is avoided, and in this way even strongly swelling or coking coals can be carbonized successfully

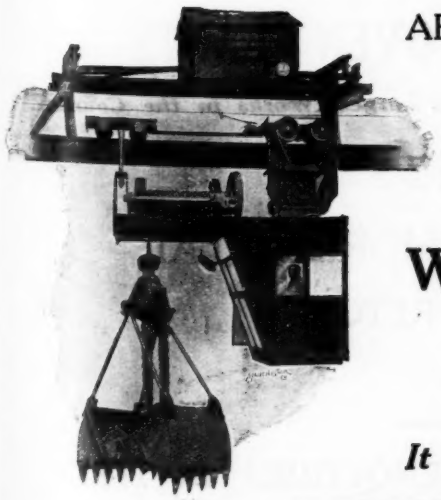
The system has been tried out on a large scale, as in the plant of the Leigh Smokeless Fuels. This plant consists of a coal washery, with drying, grinding, and briquetting machines, and two retorts, the capacity of the plant being designed with a view to treatment of 100 tons of small coal in 24 hours. The plant was started into operation during January, 1927, and closed-down for alterations during the month of July, 1927. The running of this plant demonstrated that the fuel produced had all the characteristics which had previously been shown in the small experimental units.

In the plant in question, while occasionally lump coal was passed through, the main objective was the utilization or turning to account of small coal slack, and the running of the plant was practically confined to working on briquetted material. A total quantity of some 3600 tons of briquettes was passed through the retort.

As was to be expected in a new installation of this character, many alterations were found necessary, but gradually the difficulties encountered were overcome as adjustments were made. It was, however, finally decided that constructional alterations were necessary in the retorts in order to equalize the flow of circulating gas, and that until these were done, the full output of the plant could not be realized.

The existing plant cannot as yet be spoken of as being proved economical on a large scale; but it is hoped that this will be satisfactorily demonstrated when the alterations are made and the plant is started-up again.

The fuel made on the large-scale plant from



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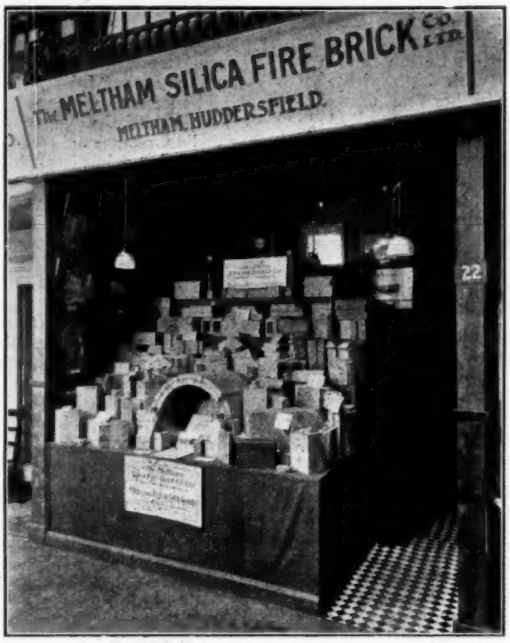


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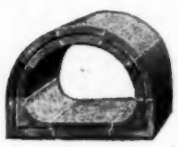
VERTICAL and SILICA  HORIZONTAL RETORTS

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briquetted material did in all cases take the place of anthracite; and there was no difficulty in disposing of the fuel for this purpose. For central heating installations, its value was, roughly, 50 p.ct. greater than a good quality of gas coke or furnace coke, while it operates in anthracite stoves in a perfect manner, and could be used with greater economy than the best anthracite. The fuel was also well received for use in the domestic grate.

The tar produced was of the characteristic low-temperature type. An analysis showed:

| | |
|---|---|
| Light oil up to 170° C. . . . . | 9·5 p.ct. |
| From 170° to 350° C. . . | 66·0 ,, |
| Residue pitch (soft) . . . . . | 23·0 ,, |

The moisture content of the tar was in general high—in some cases ruling down to 23 p.ct., and at others up to 46 p.ct. This was simply tar decanted without any attempt at dehydration; and as more urgent problems had to be attended to at the works, and all the tar produced was readily disposed of at very satisfactory prices, no serious attempts were made at treating the tar to reduce the moisture content. We are of opinion that in normal operations, by simple decantation, the moisture content would be got down to 23 p.ct.

Regarding the question of the balance-sheet of products which may be obtained from a good-class caking coal. Assuming a 7-ft. Lancashire coal, there is sufficient evidence on large-scale operations to say that with that coal there would be produced per ton of raw coal some:

14 cwt. of smokeless fuel.
22 gallons of tar.
Between 40 and 50 lbs. of sulphate of ammonia.
About 10,000 c.ft. of gas at a value of 400 B.Th.U.

As regards light oils, no evidence of value could be deduced from the large scale operations; but from small experimental tests carried out in the laboratory, it is expected that some 3 gallons of light oil or motor spirit would be procurable from this coal, in addition to that in the tar.

As to fuel consumption, it is expected that the gas from the operation will be more than sufficient to provide what is required for carbonization and power requirements when briquettes are carbonized, and a surplus of some 4000 ft. when lump coal is treated.

Regarding the question as to where it would be most advantageous to use this process, no strict lines could be laid down as to whether it would be best at a colliery, at a gas undertaking, or run independently. These are questions which could only be settled as occasions arose.

We are of opinion that our type of retort could be adopted by gas-works to advantage to permit their meeting the increasing demand for smokeless fuel, and for them to carbonize lump non-coking coals and lump coals of low coking index.

Fifty per cent. of the house coal burned to-day could be treated in such retorts without fear of sticking due to swelling.

It is generally conceded that 15 cwt. of smokeless fuel will give the same heating effect in the usual domestic grate as 20 cwt. of raw coal as burnt to-day; and provided the householder could be persuaded to pay the same price for 15 cwt. of smokeless fuel as is now paid for the 20 cwt. of the raw coal consumed, the economic equation would balance. Even the best household lump coals could then be carbonized, resulting in the production of smokeless fuel of excellent quality, and quite as satisfactory and as free from ash as the best house coals.

Such a state, however, is not yet with us; but there are many cheap grades of suitable coal which should leave a good margin for treatment, and which could give a superior and cleaner coke or smokeless fuel to what is produced to-day at the usual gas-works.

Taking such a coal equal in quality to the Lancashire 7-ft. coal, the total all-in operating costs, including depreciation and capital charges, would not exceed 6s. per ton of raw coal treated. The economic balance may be struck as follows, assuming the coal costs at 25s. per ton:

| | s. | d. | | s. | d. |
|---|---|---|---|---|---|
| Raw coal . . . . . | 25 | 0 | 22 galls. of tar at 4d. . | 7 | 4 |
| Costs. . . . . | 6 | 0 | 40 lbs. of sulphate at ½d. | 1 | 8 |
| Margin . . . . . | 3 | 3 | 3 galls. of light oil at 6d. | 1 | 6 |
| | | | 13 cwt of smokeless fuel at 1s. 6d. . . . . | 19 | 6 |
| | | | 1 cwt. of breeze. . . | 0 | 3 |
| | | | 4000 c.ft. of gas over retort requirements . . | 4 | 0 |
| | 34 | 3 | | 34 | 3 |

## THE "TURNER" RETORT.

By CHARLES TURNER.

This vertical, truncated, conical retort is made wholly of iron and steel, and is internally heated solely by superheated low-pressure steam passed into it uninterruptedly at the bottom. The material to be treated in it is introduced through a hopper above the retort which has a steam-tight valve above and below it. The treated material is passed out below the retort through a similar hopper having a steam-tight valve above and below it. The material in the retort rests on an archimedean screw placed at the base of the retort, and is allowed to sink slowly and uniformly by the slow rotation of the screw. At the top of the retort there is a vapour outlet valve so arranged that it remains closed until the steam entering the retort has raised the pressure to a desired maximum, when it opens instantly and remains open until the pressure has dropped to the desired minimum, when it closes instantly. While the valve is closed the steam is pressed into all the voids between the material, and, being practically at rest, transfers heat to the material with which it is in contact until it attains the same temperature. When the valve opens, the steam expands, drops in temperature, and rushes through the valve into condensers, carrying with it the vapours released by the drop in pressure from the material possessed of the necessary temperature to produce them. At that instant the material is actually at a higher temperature than the steam by which it was heated. The volatile therefore is released into a steam atmosphere at a lower temperature than its own temperature of formation. In this way the hydrocarbon vapours are prevented from coming into contact with anything as hot as themselves. The result is the maximum recovery of hydrocarbons in the liquid form and the minimum production or non-production of gas.

Every bituminous substance can be successfully treated in this manner, by adapting temperature, pressure, and time conditions to suit each particular substance.

A plant has been in continuous operation throughout the year 1927, treating 10 tons of coal daily. The coal is of low grade by reason of dirt bands in it, and contains 13 p.ct. of ash. It is sold by the colliery at 9s. per ton, and yields 30 gallons of oil and 12 cwt. of smokeless fuel containing less than 5 p.ct. of ash. These products from one ton of coal together realize 27s. 6d. at works. On an installation treating 500 tons daily, the all-in operating costs will be under 5s. per ton of coal treated. (The present costs are over 15s. per ton.) Under such conditions either product would realize enough to pay for the coal and the cost of conversion.

The solid fuel is readily sold to bakers, riveters, householders, &c. It ignites readily and burns freely without smoke in the open grate.

There is no emulsion of oil and condensed-steam water. Separation takes place readily and quickly. The oil is water-free.

It is probable that the process will develop independently of collieries, and will tend to become the principal outlet for coal.

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